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EFFECTS OF EXHAUST FROM TWO-CYCLE OUTBOARD ENGINES

Rensselaer Polytechnic Institute

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16. ABSTRACT

A combined laboratory and field study has been made to determine the extent of pollution arising from the operation of two-cycle outboard engines in an oligotrophic/mesotrophic lake. The fate of the exhaust products discharged to a lake environment has been studied. Three bays having different boat usage were compared.

Attempts have been made to examine the quantities of exhaust products found in the water column, the water surface, and in the bottom sediments. The role of such mechanisms as microbial decomposition, evaporation, and adsorption has been studied. Results of these studies have shown very low levels of hydrocarbons, other than from natural sources, in sediments and the water column. Somewhat greater quantities were found in surface films. The microbiological studies and evaporative studies indicate that these mechanisms play a significant role in the dispersion of engine exhaust products.

The relatively low levels of exhaust products found appear to be related to both purification mechanisms and to low levels of boating stress. Such indicators as surface film concentrations and threshold odor numbers follow boating usage patterns rather closely in the bays studied.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
*Exhaust emissions, *Hydrocarbons, Limnology, *Outboard engines, Evaporation, Adsorption	Surface films, Lake George	13B

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment -- air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and

- a search for ways to prevent contamination and to recycle valuable resources.

Research studies on effective waste management of transportation and recreational sources have involved the development of technology for the economic treatment of wastewaters (including bilge and ballast discharges) from watercraft. Emphasis of investigations have been on treatment effectiveness, operation and maintenance requirements, safety aspects, and overall costs.

A. W. Breidenbach, Ph.D.
Director
National Environmental
Research Center, Cincinnati

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SECTION I - SUMMARY AND CONCLUSIONS

1. The infrared spectrometry method used for hydrocarbon measurement preferentially determines non-polar material, but cannot distinguish between outboard engine emissions and naturally occurring, non-polar extractables, all of which are reported as "hydrocarbons".

2. "Hydrocarbon" levels for Florisil treated surface samples ranged from 1.0-5.0 mg/m^2. Concentrations followed the levels of boat usage.

3. The "hydrocarbon" (CCl_4 extractables) levels found in water column samples in the test bays were uniformly low during the 1972 boating season, indicating the presence of very little soluble or dispersed products from exhaust. Levels were generally less than 0.1 ppm.

4. There is a significant difference in numbers of water column microorganisms between the bays throughout the year.

5. Growth of heterotrophic lake cultures and a pseudomonad isolated from Dunham Bay was usually less on petroleum agar than on nutrient agar.

6. Warburg respirometer studies show that the presence of oil does not significantly change the oxygen uptake rate of lake sediment.

7. Maximum endogenous oxygen uptake rate of the sediment from Dunham Bay Station 4 occurs during the spring growing season. High oxygen uptake capacity of the sediment from Dunham Bay Station 4 over the July 4th holiday is seen as a result of boating activity.

8. The metabolic activity (as heterotrophic potential) of the heterotrophic microflora from Dunham Bay Station 2, when normalized to unit microbial cell activity, appears significantly greater than that of any other station. In general, all Dunham Bay stations show more activity than Echo Bay stations.

9. Statistical analysis of the data indicates that 43% of the variation of the log value for column organisms can be explained by the other variables in the statistical model.

10. The study has provided information on the variation of major algae species present in the test bays. The data do not afford any significant correlation between kinds and number of algae present, and boat traffic.

11. $C^{14}O_2$ fixation by indigenous algae is enhanced in the presence of 1-3 ppm crankcase drainage or 1-5 ppm oil gas (1:50) mixture but is inhibited at higher concentrations.

12. At a concentration of 5 ppm of carbon from water soluble extract from crankcase drainage, the $C^{14}O_2$ rate of Mycrocystis aeruginosa is inhibited, whereas Anabaena flos-aquae and Selanastrum capricornutum are not materially affected.

13. The level of water soluble extract from crankcase drainage that produced a stimulation of specific growth rate was 1 ppm for Microcystis aeruginosa, 5 ppm for Anabaena flos-aquae, and 35 ppm for Selanastrum capricornutum.

14. The length of the log period in the algal growth curves reflected the levels of water soluble extract from crankcase drainage. Anabaena flos-aquae showed the greatest effect. Maximum standing crop, however, was not materially affected.

15. The benthic fauna of Dunham Bay did not appear to be essentially different from Smith or Echo Bays. Species variation, density, and distribution among the bays and specific stations, however, apparently can be attributed to natural factors (e.g. vegetation, bottom type) rather than exogenous materials, low dissolved oxygen or toxicity. The diversity index ($\bar{d}$) values and variation in species for Dunham Bay were somewhat greater than for the other bays studied. Although of higher density, the benthic fauna were characteristic of that described for the littoral and sublittoral zones of oligotrophic lakes.

16. The bioassays indicate that materials discharged from two-cycle marine engines are highly toxic and have a 24 hour TL_{50} of approximately 1.0 mg/l for certain benthic macroinvertebrates. The TL_{50} for more extended time periods is not significantly larger.

17. The results of threshold odor number tests seemed to relate closely with levels of boat usage. Results corresponded with chemical tests, but reacted more strongly and rapidly.

18. Adsorption tests indicated that the sediments from both Echo Bay and Dunham Bay are capable of adsorbing exhaust products and carrying them to the bottom. Sediments from Echo Bay had a greater tendency to adsorb exhaust products than did sediments from Dunham Bay. The presence of hydrocarbons in bottom sediments from sources other than natural sources was very low.

19. A considerable fraction of exhaust products can be expected to evaporate from the water surface to the air at temperatures normally encountered during periods of the year when boating is at a maximum level. For the exhaust products studied, it was found that approximately 65% was removed from the surface by this mechanism.

20. Statistical analysis of portions of the data has been made to elucidate variations in certain components of the lake system, and to identify factors having an influence on such components. Such identification does not necessarily imply any absolute cause and effect relationship. This work has led to the following conclusions:

    a) Based on limited results, the level of phytoplankton depends upon temperature and dissolved oxygen, and decreases as these factors increase.

    b) Analysis indicates that there may be correlations between phytoplankton and surface microorganism levels, surface temperature and surface dissolved oxygen. With the given data no conclusions could be reached regarding the association between hydrocarbon levels and phytoplankton levels.

    c) Analysis of data related to water column microorganisms, hydrocarbon levels and column temperature indicates that there may be associations between the variables.

    d) Examination of the relationship between surface microorganism levels, hydrocarbon levels, surface dissolved oxygen and surface temperature indicates that after the response variable (surface microorganism) has been adjusted for temperature, the contributions due to hydrocarbon and dissolved oxygen are negligible.

21. The studies have indicated that a normal boating concentration of about 20 boats per square mile may be expected on Lake George. The concentration may reach a value of 300 boats per square mile during holiday weekends. The resulting concentrations of exhaust products which result from an equilibrium of inputs and outputs from the lake system as indicated within the scope of this study appear to be low enough to cause no discernable effects of a permanent nature.

SECTION II - RECOMMENDATIONS

1. Refinements in analytical techniques need to be developed. For the low levels of hydrocarbons and products from the exhaust encountered in water, sediments and in various forms of life, the need for improvements in technique and methods is paramount.

2. Further improvements in methods of sampling for surface films need to be developed. This can be developed in the laboratory but needs to be proven in the field.

3. Characterization of the chemical components of discharges from two-cycle outboard engines should be made.

4. Improved data on inputs to the lake system can be expected, as information from recent opinion surveys by users of Lake George is computerized. This information should be used to refine the evaluation of the exhaust product problem.

5. Intensive heterotrophic potential studies should be made with sediments and microflora from water samples in controlled experiments in which oil and exhaust water is added at various levels with and without additional nutrients at various pH values, temperatures, and dissolved oxygen concentrations. These studies will produce mechanistic information with respect to the influence of these pertinent variables on the turnover capacity of the natural microflora.

6. In order to include the smaller species of algae, plankton tow samples need to be supplemented with VanDorn bottle samples. Dominant algal species, like Fragilaria, Asterionella, etc., should be isolated and unialgal bioassays performed to determine the effect of exhaust products on each species.

7. The studies of toxicity effects by engine discharges on macrobenthic invertebrates should be continued. Continuous flow bioassays should be conducted to determine precise 96 hour TL_{50}'s for selected macroinvertebrates exhibiting a range of tolerances.

8. As improved analytical techniques become available, studies should be extended towards quantifying the amounts of individual hydrocarbons and other products found in bottom sediments which have their origins in engine discharges, including the establishment of baseline levels.

9. Further work needs to be done on the evaporative studies by investigating the evaporation of exhaust products taken under a broad spectrum of operating conditions. This can be done by collecting samples of exhaust products from tank tests.

SECTION III - INTRODUCTION

In recent years increased attention has been directed towards the preservation of the chemical, physical and biological quality of our natural waters. The rapidly growing use of two-cycle outboard engines has focused attention on the possibility that the exhaust from these engines may be a significant source of pollution in areas where their use is extensive. Hence, it is important to determine the extent of this form of pollution and its influence on the environment, in order to determine acceptable limits of discharge. These limits must be based on: (1) the physical and chemical processes involved in removing the pollutants from their area of influence; (2) the ability of the body of water with its accompanying flora to degrade the pollutants; and (3) a residual that is unobjectionable in terms of water usage and/or ecological balance.

Purpose and Scope

In the present study, both field and laboratory work have been conducted for the purpose of establishing the level and nature of the pollution from two-cycle outboard engines in an oligotrophic/mesotrophic lake system. In addition, work has been directed towards establishing the fate of the exhaust products discharged, and the interactions that occur between these products and the lake environment.

The lake selected for field studies has been Lake George in Upper New York State. Lake George is a natural body of water and is located in the southeastern portion of New York's Adirondack State Park. The lake is approximately 32 miles long and varies in width from 1 to 3 miles. Its surface area is 44 square miles and has a drainage area of 234 square miles. The average discharge from the lake is 295 cfs based on 22 years of records. There are 109 miles of shoreline with many small bays. The maximum depth of the lake is about 195 ft. It is an oligotrophic lake with the exception of certain mesotrophic bays and the mesotrophic area at the southern tip, bordered by Lake George Village. Previous work by the Lake George Study Group from Rensselaer Polytechnic Institute provides a background of chemical and biological data on the lake.

The lake is a very popular resort area and has many fine attractions for tourists who come regularly from as far as New York City and Montreal. The permanent population of the Town of Lake George was 2603 in 1970. The permanent summer population was 14,845 during the same year. The total summer population, including transients and visitors, was estimated to be close to 40,000 people. With the expansion of transportation facilities to the Lake George area, there has been an increase in both permanent and transient population in this region.

Because of the emphasis on recreational usage, the number of boats on Lake George has been considerable. A number of surveys and counts have been reported from various sources. In a recent survey conducted through a joint effort of the Lake George Park Commission and the Warren County Sheriff's Patrol, and reported in a private communication by Mr. James O'Brien, Director of Marine and Recreational Vehicles, New York State Department of Parks and Recreation, it has been estimated that on a typical holiday weekend, the number of boats is in the range of 12,000 to 14,000. It has further been reported that the normal loading of boats navigating in the water at "any given hour" will be about 800 to 1000. These estimates have been confirmed by aerial spot checks made by the Lake George Park Commission, and more recently, by aerial photographs made by Rensselaer Polytechnic Institute personnel. It may be noted that the number of boats registered in the Lake George watershed is approximately 8000.

In studying the effects of outboard engine exhaust products on the lake system, comparative studies have been made in three Lake George bays having widely different use patterns. Counts of boats using these bays have been made to establish relative levels of use. The bays studies are: (1) Smith Bay having light traffic (5-20 boats/day); (2) Echo Bay having a restricted entry which limits traffic (40-80 boats/day) almost entirely to that from local residents; and (3) Dunham Bay which has heavy boat usage (400-700 boats/day).

Dunham Bay is the largest of the three bays and is located in the southern part of the lake as shown in Fig. 1. The bay has an area of 0.11 square miles and is serviced by two marinas. Based upon aerial surveys, the number of boats normally docked within the bay and in the creek feeding the bay is about 245 during the height of the summer season. On holiday weekends the number may be increased by about 20% to approximately 295. The amount of gasoline used by the largest marina in the bay has been reported as about 30,000 gallons during 1971. During the peak July 4th weekend, a count of boats entering and leaving the entrance to the bay was made and found to be about 690 boats per day, with a peak traffic count of 89 boats per hour. The average horsepower used was estimated to be 70. On a more typical summer weekend, the number of boats in and out of the bay was 410 boats per day. This number, of course, varied greatly depending upon weather conditions and the time of the year. (see Fig. 2)

Echo Bay is a narrow bay having restricted access to the lake. It has an area of about 0.04 square miles and one fuel pump is located here. Because of its shape and location, the boat traffic in and out of the bay is usually limited to local residents. The number of boats normally docked in the bay is about 31. Boat counts of boats in and out of the bay have indicated a peak figure of about 77 boats per day, and about 40 boats per day on a more normal weekend. (see Fig. 3)

Smith Bay has a wide entrance to the bay and an area estimated to be about 0.02 square miles. No fuel pumps are provided in this bay. The major traffic consists of boats used by the Fresh Water Institute plus a few boats of other residents. The boats docked in the bay seldom exceed 10. Boat traffic in and out of the bay on a peak weekend has

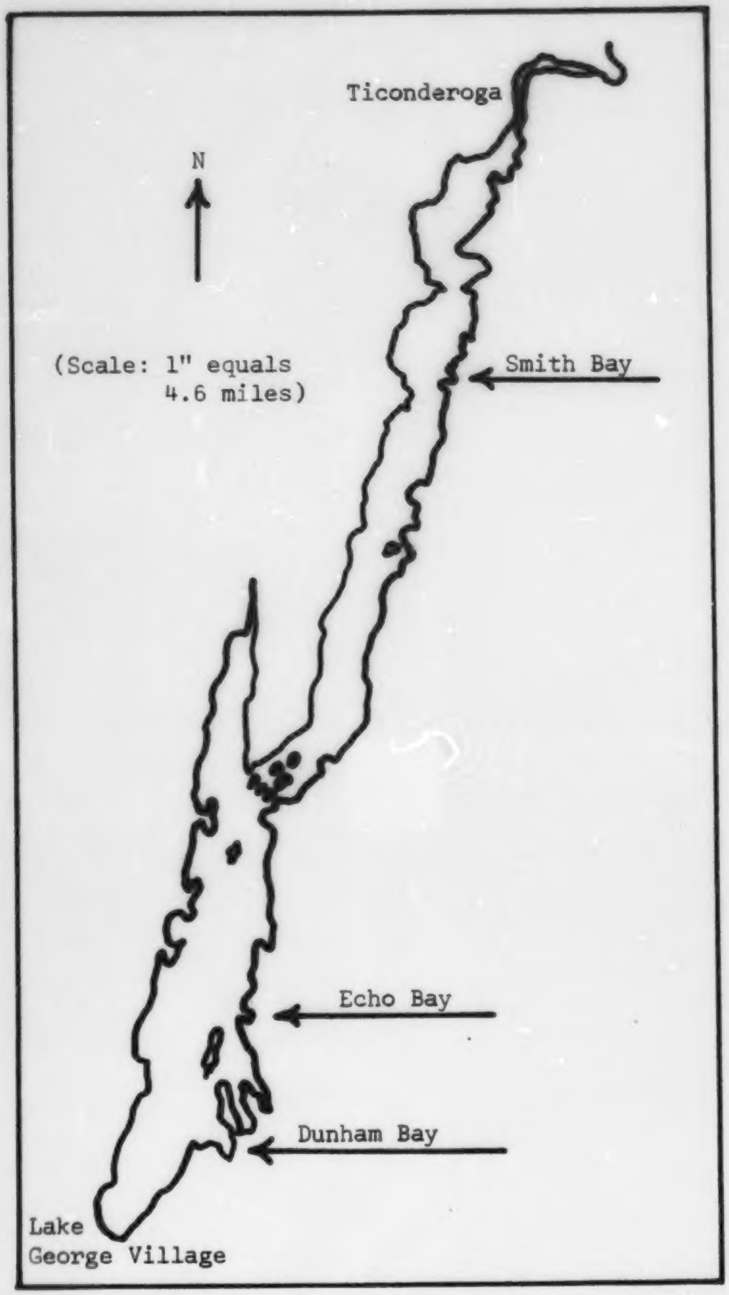
Ticonderoga
N
(Scale: 1" equals
4.6 miles)
Smith Bay
Echo Bay
Dunham Bay
Lake
George Village

Figure 1 - An Outline Map of Lake George Showing the Three Bays under Investigation

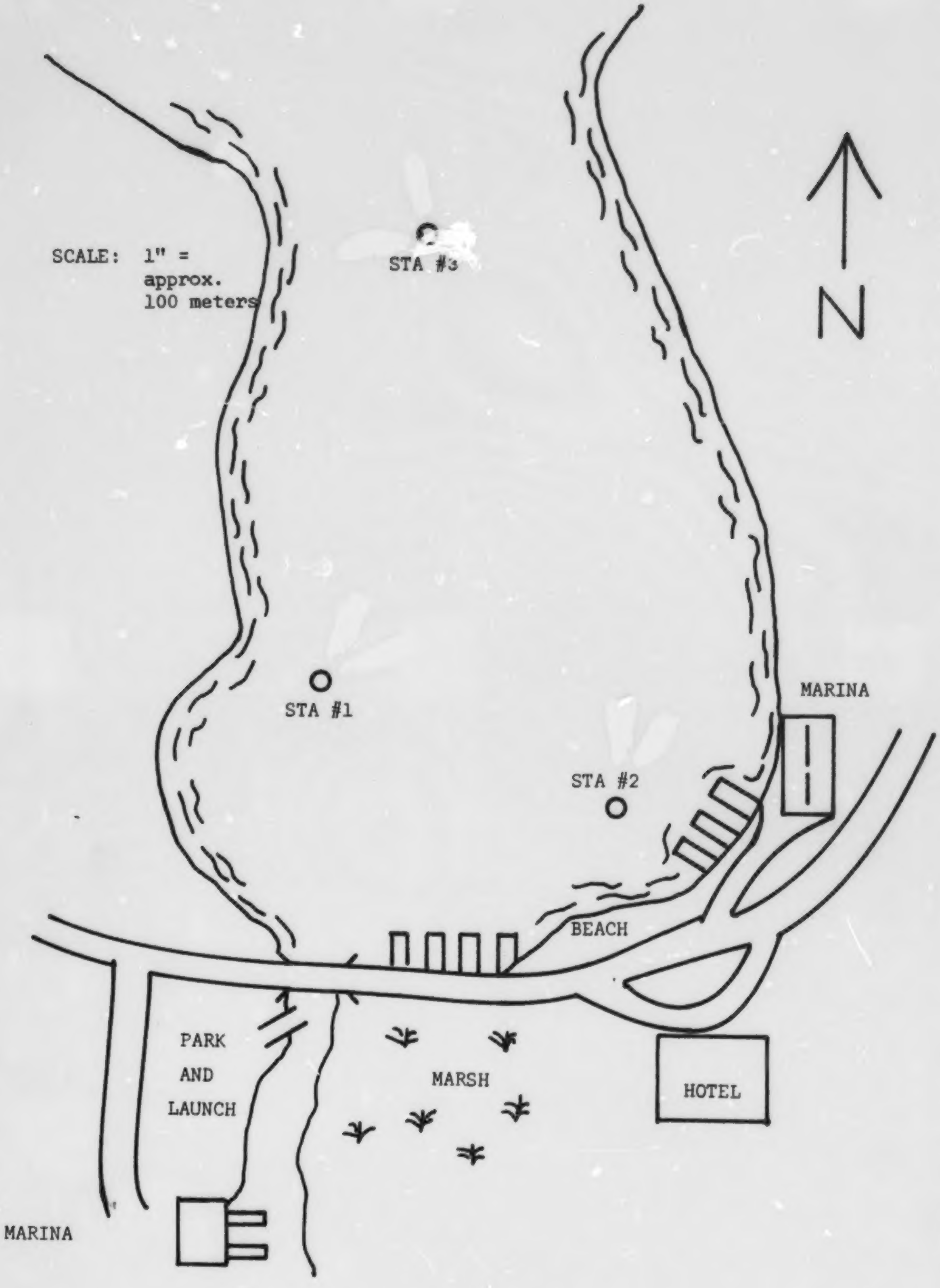
SCALE: 1" = approx. 100 meters
STA #3
N
STA #1
MARINA
STA #2
BEACH
PARK AND LAUNCH
MARSH
HOTEL
MARINA

Figure 2 - Sketch of Dunham Bay Showing Location of Sampling Stations

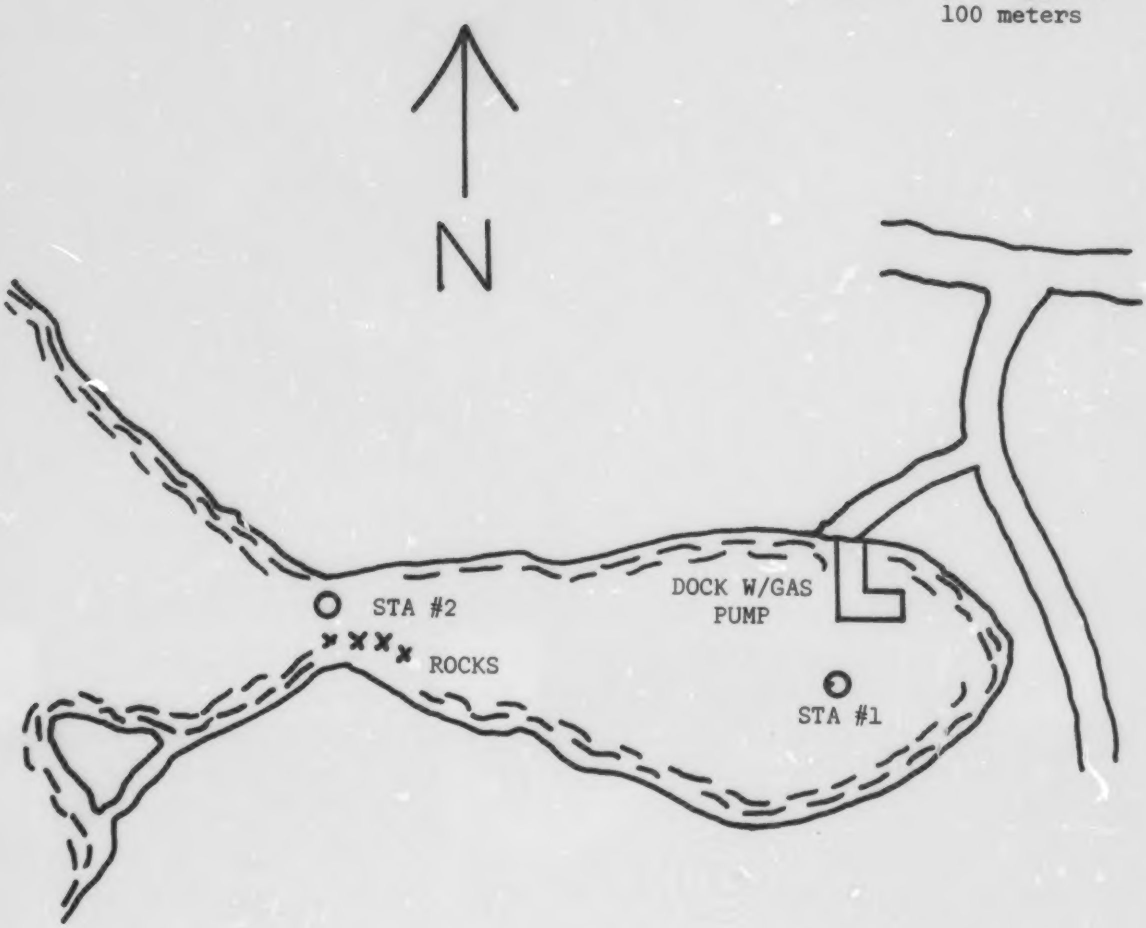
SCALE: 1" = approx. 100 meters
N
STA #2
ROCKS
DOCK W/GAS PUMP
STA #1

Figure 3 - Sketch of Echo Bay Showing Location of Sampling Stations

been estimated as 18 boats per day. On a typical weekend, the number is closer to 7 boats per day. (see Fig. 4)

It is recognized that boat usage may vary over wide limits depending upon many factors. For instance, in very bad weather, the usage may be zero. However, the values reported and summarized in Table 1 are typical of summer usage in reasonably good weather, and are indicative of the relative stress in the bays studied in this work.

In the present study, a sampling program has been developed that has been related to the intensity of boat usage. Intensive sampling has been conducted during the summer months with particular emphasis immediately before, during, and immediately after holiday weekends. Water quality determinations have been made on samples collected on a routine basis. Particular emphasis has been directed towards establishing current levels of hydrocarbons at the water surface, in the water column and in the sediments, and in determining those factors which enhance or limit microbial degradation of hydrocarbons. A variety of sampling techniques and analytical methods have been examined, evaluated, and modified where necessary to suit particular needs.

The scope of the field studies has also incorporated estimates of the effects of engine discharge on primary production. Speciation and numbers of periphytic and planktonic algae have been investigated using several techniques. Speciation and enumeration of benthic macroorganisms have also been made on a limited scale.

To provide support data for the primary studies, a number of limited studies have been conducted in the field. These include studies of currents in the bays under investigation, and determination of odor levels and odor variations in the waters of the study bays.

A major effort has been directed to laboratory studies. Work has been devoted to studying the kinetics of removal of engine discharge by biological oxidation, physical adsorption to sediments and other substrates, and by volatilization from water. Associated with much of this work has been the need for modifying existing experimental techniques, and for developing new techniques as dictated by local circumstances.

Source of Discharges from Two-Cycle Engines

By far, the majority of the outboard engines in use are two-cycle models. In this type of engine a gasoline-oil mixture is used both as a fuel and as a lubricant. The engine combines, in one stroke, both fuel intake and exhaust. Since both intake and exhaust valves are open at the same time, a portion of the fuel is exhausted directly in an unburned or partially burned state during this part of the cycle. An additional characteristic of two-cycle engines which results in discharge is the lubrication system that is used. In contrast to a forced feed system as used in most four-cycle engines, where oil is delivered directly to

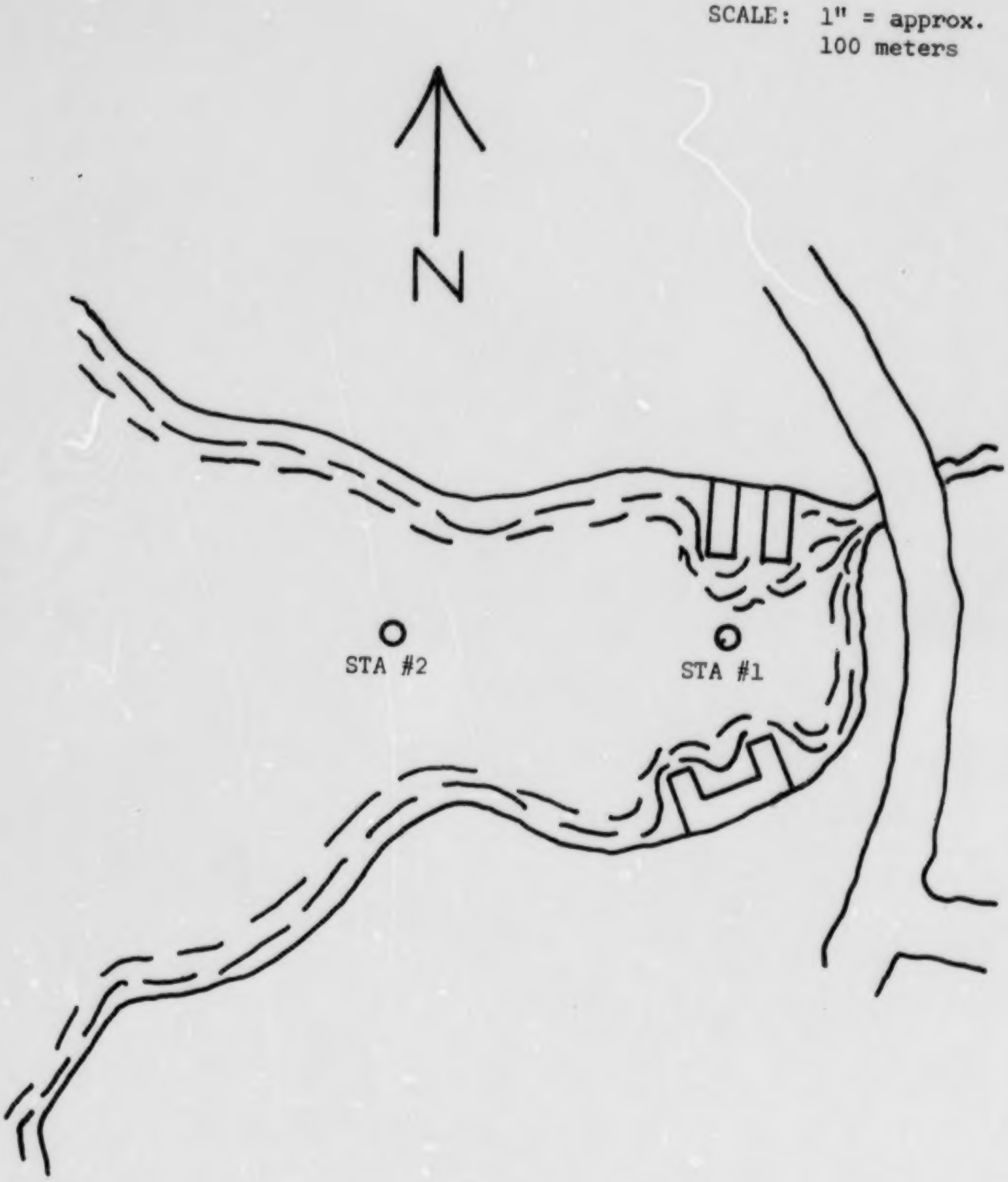
SCALE: 1" = approx. 100 meters
N
STA #2
STA #1

Figure 4 - Sketch of Smith Bay Showing Location of Sampling Stations

Table 1

Boat Usage on Lake George

Bay	Fuel Pumps	Area Square Miles	Boats Docked	Traffic-Boats/Day Peak	Traffic-Boats/Day Typical
Dunham	2	0.11	295	690	410
Echo	1	0.04	31	77	40
Smith	0	0.02	10	18	7

engine parts from a crankcase reservoir, lubrication is achieved in the two-cycle engine by mixing the lubricating oil with the gasoline fuel. The gas-oil mixture is fed to the engine via the crankcase where a portion of the fuel is condensed. Because of the much lower volatility of the oil, the oil predominates in the material which coats the engine parts and accomplishes the desired lubrication. Since a continuous supply of the gas-oil fuel mixture is fed to the engine, the oil tends to accumulate in the engine. To prevent an excessive build-up, engines are provided with a bleed valve which directs the excess oil to the exhaust line and, hence, to the water.

Review of Related Work

Efforts have been made by a number of investigators to measure the quantity of exhaust products discharged by outboard motors under a variety of operating conditions. Studies conducted at Rensselaer Polytechnic Institute have indicated that for a moderately sized engine, freshly tuned, the fraction of fuel used that was discharged varied from about 3% at high speeds to about 26% at low speeds (69). Similar studies made by Foster D. Snell, Inc. indicated that between 10% and 33% of the fuel charged was discharged in the exhaust (71). For engines which had not been freshly tuned, the fractions discharged were somewhat higher.

While attempts are currently being made by engine manufacturers to reduce the amount of exhaust products discharged by some engine models, the success of these attempts remains to be proven. As pointed out by Muratori, the rate of increase of total amount of discharge from outboard engine usage may well offset any improvements in engine design (49). Muratori also pointed out the fact that some 50% of all outboards presently owned are at least eight years old.

A number of investigators have noted effects from the discharge of motor boat exhaust (18,21,26). English et al. (22) have estimated that for every gallon of fuel consumed by outboard engines, between 300,000 and 500,000 gallons of water are required as dilution to provide adequate protection from fish tainting. Others have noted the apparent persistence of oily discharges from outboard motors and the effects on the biological life in natural wastes (17). Stewart has briefly reviewed some of these efforts (77). In the earlier Rensselaer study, preliminary work on the biodegradability of engine fuel and exhaust products was made (69). Results indicated that these materials are capable of supporting microbial growth, and that growth rates are limited by available oxygen.

SECTION IV - WATER QUALITY MEASUREMENTS INCLUDING HYDROCARBON ANALYSES

INTRODUCTION

The evaluation of effects from two-cycle outboard engines is based on the actual levels of exhaust products present in the study bays of Lake George. Samples collected from the bays were analyzed for exhaust products, as "hydrocarbon", to establish both levels present and fluctuations which could occur as a result of varying degrees of boating activities.

The term "hydrocarbons" has been operationally adopted and does not infer identification of exhaust products. The materials measured are those which can be extracted from an acidified sample using a non-polar, halogenated solvent, those not retained on a Florisil column, and those containing saturated carbon-hydrogen bonds.

This analytical approach to determining "hydrocarbon" material has generally been applied to environmental conditions which include obvious oil pollution, whether by design or accident. While the method is applicable to extended field studies, it is not specific for exhaust products, so that other materials normally present could contribute significantly to the extractables at low levels of outboard emissions.

Water quality parameters have been determined on bay samples where biological co-studies were underway. The parameters do not relate directly to the levels of "hydrocarbons" as exhaust wastes, but are pertinent to the utilization of "hydrocarbons" as a carbon source by bacterial decomposers.

PROCEDURE

Sampling

In the Lake George study, all field sampling involving "hydrocarbon" samples were conducted from a twelve-foot aluminum boat. The boat was fitted with a small electric motor, but a pair of oars often proved more useful. A truck was used to transport the boat to and from the bays so that an outboard engine was not required at any time.

From previous work conducted at R.P.I. (3), it had been determined that more than 90% of outboard motor exhaust accumulated in a surface film. Sampling of the water column would then present a deceptively low level of "hydrocarbon" concentration, which would be dependent upon the surface to volume ratio.

The sampling approach taken in this study was, therefore, to collect separate film and bulk samples at each station. Water column samples were collected with a conventional VanDorn sampler, having a six-liter volume. The sampler was placed through the surface film, closed, and cocked under water. Samples were collected in four-liter pyrex bottles which were marked at the three-liter level. Water quality samples were collected in polyethylene containers of one-quart size.

Perhaps the most difficult phase of "hydrocarbon" measurement is the collection of surface film samples. In his work, Kremer (40) used two methods. The first employed a four-liter pyrex bottle which was dipped length-wise to a depth at which the surface film flowed into the mouth of the bottle. By gradually tipping the bottle deeper, a three-liter sample could be collected. However, the surface area this volume represented could not be calculated. The second method tried by Kremer utilized an aluminum ring 17.5 cm i.d. and 7.6 cm deep. In sampling, a strip of Whatman #1 filter paper was placed around the interior surface and held in place by wetting. The ring was dipped to a depth where the surface film lay within the width of the filter paper. A few drops of detergent solution were placed in the center of the enclosed film driving the film toward the paper on which it was collected. The "hydrocarbons" could then be recovered by extracting the paper in a Soxhlet apparatus. While the ring appeared to work well when the surface was still, any surface disturbance was exaggerated within the ring, resulting in a distinct vertical "pulsing" or surge effect. This action made the ring virtually useless with the usual lake surface.

As a feasible solution, a stainless steel pot (see Fig. 5), 25.6 cm i.d., 11.5 cm deep and fitted with a 5 cm hole in the bottom was prepared and employed. Beneath the hole, a threaded, circular aluminum fitting was mounted which accepted an 11 cm length of PVC pipe. In the field, the pot was first covered, pushed through the surface film, and then uncovered. Holding the pot with the handle above the surface, the pot was then maneuvered to an undisturbed area and drawn up through the surface. The large bottom opening allowed relatively rapid upward motion without causing the surface film to disperse. When the pot had been raised through the surface a sufficient distance, i.e. 1/2 to 2/3 pot depth, the pipe was closed with a No. 11 stopper, and the pot removed from the water. The sample was then poured into a one or two-liter pyrex bottle, and the stopper set aside. All interior metal surfaces of the pot were then rinsed down with solvent using a 10 ml Manostat Mini-Pet syringe. Generally, a total of 50 mls of solvent was sufficient for this operation with all rinsings being added to the sample.

Although simple in construction, the sampling pot allowed a known surface area to be entrapped under most surface conditions, and provided a minimum of film disturbance in quiescent conditions.

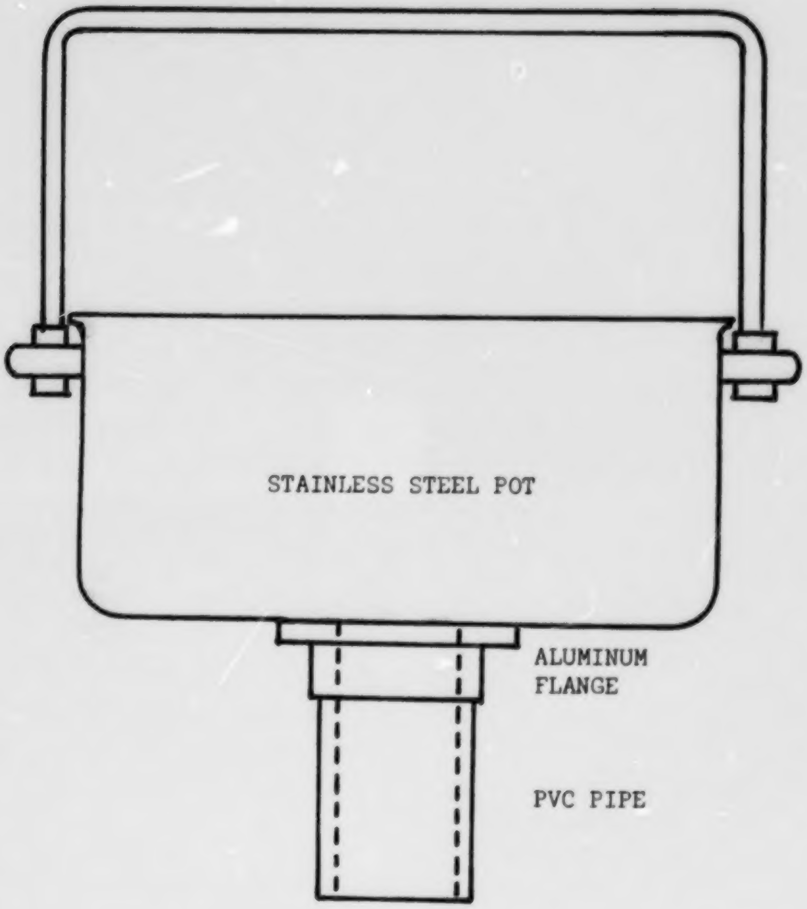
STAINLESS STEEL POT
ALUMINUM FLANGE
PVC PIPE

Figure 5 - Surface Film Sampler

Analytical Procedures

The measurement of "hydrocarbon" material is based on the API infrared procedure (2). Both carbon tetrachloride and trichlorotrifluoroethylene (Freon TF, Dupont) were used as extraction solvents during the course of the study. Freon TF was substituted primarily for its lower toxicity since the surface sampling required use of the solvent in the field. Spectranalyzed and reagent grades of carbon tetrachloride (Fisher Scientific) were found to be of equal quality so long as the latter was shipped in glass containers. A five-gallon can of the reagent-grade solvent gave an IR response greater than many samples and was rejected. Freon TF was found to absorb more strongly than carbon tetrachloride at the analytical wave length, but the standards prepared gave transmittancies similar to those prepared in carbon tetrachloride.

The "hydrocarbon" materials were measured against standards prepared from outboard motor oil (Mobil Oil Corp.) since evaporation studies (see Section XII) indicate that gasoline would be rapidly lost to the atmosphere. Outboard motor oil is the most appropriate material for calibration, since it has a definite composition. While outboard motor exhaust waste would be even more appropriate, its composition can be drastically altered by the efficiency of the engine, which is a function of engine tuning and speed (69).

Measurements of extracts were made on a Beckman IR-20 spectrophotometer using 50 mm cells with CaF_2 windows. While the extended light path increased the sensitivity of the measurements, the cell (Barnes Engineering) had two deficiencies. The cell volume was 32 mls which limited the degree of concentration possible and the long light path minimized the usable IR wave lengths because of solvent absorption. Spectral areas where aromatic compounds are most active were "blind". The analytical wave length was set at maximum absorbance in the vicinity of 3.42 microns using the standard solutions. Other wave lengths were not considered because of the small response of the samples.

Both water column and surface film samples were extracted in the same manner. The samples were extracted in the glass sample containers following acidification to pH 2 with concentrated HCl. Sodium chloride was added at 5 gms per liter. Fifty mls of solvent were added to approximately 3 liters of water column sample while the film samples were extracted with the field rinsings already in the containers. Sample volumes were determined by weight.

All samples were shaken vigorously for two one-minute periods and allowed to stand overnight for separation. One technician was assigned to the extraction procedure to maximize reproducibility. Film samples were transferred to a one-liter separatory funnel and the solvent phase drawn off into a graduated cylinder for volume measurement. Twenty-five mls of solvent were drawn from the column samples by pipette and made up to 50 mls with additional solvent. All extracts were dried over 5 gms of anhydrous sodium sulfate. Initially, dried extracts were measured, then evaporated to approximately 25 mls at room temperature (20-23°C). The procedure assumes the absence of materials which are volatile at this temperature range since the bulk of the sampling had occurred during the summer boating season. Extracts were then passed through a one cm diameter column packed with 5 gms of Florisil and made up to 50 mls with column washes for IR analysis.

Samples taken for water quality measurements were filtered through 0.45 micron membrane filters (Millipore Corp.) upon return to the laboratory. Alaklinity, pH, total phosphorus and total kjeldahl nitrogen were determined on the unfiltered samples, with nitrate and total soluble phosphorus being determined on the filtered samples.

Phosphorus results were obtained with the ascorbic acid procedure (73) following persulfate oxidation. Nitrate was determined, following reduction on a copperized-cadmium column, by a colorimetric nitrite procedure (94). Kjeldahl-nitrogen employed the usual digestion step (73), but the ammonia was determined using an Orion electrode, following addition of an alkaline reagent to convert all NH_4^+ present to NH_3 and which complexed mercuric ions with iodide (55).

EXPERIMENTAL RESULTS

Tabulated data for Dunham, Echo and Smith Bays for the 1972 boating season have been presented in Tables 2-8. The following data have been presented:

1. "Hydrocarbons" are reported in milligrams of oil per square meter of surface (mg/m^2) in the film, and milligrams of oil per kilogram of sample (mg/kg) in the column.
2. Alkalinity (ALK) is reported as milligrams of $CaCO_3$ per liter (mg $CaCO_3$/l).
3. Total phosphorus (TP) and total soluble phosphorus (TSP) are reported in micrograms P per liter (μgP/l).
4. Total kjeldahl nitrogen (Kj-N) and nitrate (NIT) are reported in micrograms N per liter (μgN/l).
5. Temperature (Temp.) is reported in °C.
6. Dissolved oxygen (D.O.) is reported in milligrams O_2 per liter (mg O_2/l).

In general, "hydrocarbon" levels in the water column were less than 0.1 mg per kg. Column samples would indicate whether significant amounts of the outboard exhaust were soluble to any extent, but this does not appear to be the case. From Table 9, "hydrocarbon" recoveries at this level are less than two-thirds. However, taking the probable losses into account, the column levels still remain very low.

Table 2 - Water Quality Data

Dunham Bay: Station 3 - 1972

				"Hydrocarbons"							
Date	Day	Temp. °C	D.O. mg O_2/l	Surf. mg/m^2	Col. mg/kg	pH	ALK mg $CaCO_3$/l	TP µg P/l	TSP µg P/l	Kj-N µg N/l	NIT µg N/l
3-30	Th	-	-	-	<0.1	6.80	22.5				
5-2	T	-	-	3.2	<0.1	7.11	22.9				
6-1	Th	10.0	12.5	2.2	<0.1	7.52	28.5	2.8	<2.0	117.	47.0
6-9	F	14.5	10.5	2.4	<0.1	7.22	23.5				
6-12	M	13.0	10.4	1.9	<0.1	7.29	24.5	14.2	3.1	267.	48.5
6-16	F	11.8	10.0	2.4	<0.1	7.36	24.5				
6-19	M	15.0	9.8	2.4	<0.1	7.37	24.1	6.6	<2.0	225	3.2
6-23	F	15.6	9.7	1.8	<0.1	7.52	24.2				
6-26	M	16.5	8.0	1.8	<0.1	7.48	28.5	18.8	2.6	188.	6.1
7-1	S	19.0	8.2	2.4	<0.1	7.31	24.6	7.3	4.6	183.	18.5
7-3	M	18.0	8.6	4.6	<0.1						
7-4	T	19.0	7.9	2.4	<0.1	7.22	25.5	7.1	7.4	148	63.0
7-6	Th	18.9	8.1	1.7	<0.1	7.50	26.1	8.0	7.7	170.	45.0
7-10	M	19.9	7.8	6.4	<0.1	7.26	25.7	7.4	6.3	145.	8.7
7-14	F	20.5	8.7	2.8	<0.1	7.19	21.6				
7-17	M	20.5	8.9	<1.5	<0.1	7.37	21.6				
7-21	F	23.5	9.4	<1.5	<0.1	7.23	21.6				
7-24	M	-	-	<1.5	<0.1	7.11	25.4	11.1	3.7	153.	3.5

Table 2 (continued)

Date	Day	Temp. °C	D.O. mg O_2/l	"Hydrocarbons" Surf. mg/m^2	"Hydrocarbons" Col. mg/kg	pH	ALK mg $CaCO_3$/l	TP µg P/l	TSP µg P/l	Kj-N µg N/l	NIT µg N/l
7-28	F	24.5	8.6	2.7	<0.1	7.45	23.4				
7-31	M	24.0	8.5	2.8	<0.1	7.23	22.3	6.0	3.1	191.	3.6
8-7	M	22.0	8.9	4.8	<0.1	7.31	24.3	13.1	6.3	130.	3.5
8-16	W	21.5	9.8	4.3	<0.1	7.20	23.0	10.3	5.4	220.	10.8
8-21	M	22.0	10.1	1.9	<0.1	-	-	6.6	3.1	368.	5.5
8-28	M	23.0	9.1	2.9	<0.1	7.37	22.4	8.8	<2.0	376.	4.7
9-4	M	21.9	8.4	<1.5	<0.1	7.38	23.8	31.3	<2.0	264.	4.2
9-11	M	20.9	8.2	<1.5	<0.1	7.17	23.0	5.1	3.4	212.	5.0
9-18	M	19.8	9.4	<1.5	<0.1	7.12	22.5	6.0	4.0	267.	12.7
9-25	M	17.2	9.6	<1.5	<0.1	7.53	22.7	20.2	-	215.	8.9

Table 3 - Water Quality Data

Dunham Bay: Station 2 - 1972

				"Hydrocarbons"							
Date	Day	Temp. ^{o}C	D.O. mg O_2/l	Surf. mg/m^2	Col. mg/kg	pH	ALK mg $CaCO_3$/l	TP µg P/l	TSP µg P/l	Kj-N µg N/l	NIT µg N/l
5-2	T	-	-	<1.5	<0.1	7.03	24.4				
6-1	Th	13.0	12.6	2.2	<0.1	7.45	25.3	14.5	9.1	146.	7.8
6-9	F										
6-12	M	14.0	10.4	2.3	<0.1	-	-	19.1	9.7	221.	156.0
6-16	F										
6-19	M	15.5	10.3	2.4	<0.1	7.47	24.9	5.1	2.0	149.	6.2
6-23	F	16.0	10.7	<1.5	<0.1	7.57	19.0				
6-26	M	17.2	7.9	1.7	<0.1	7.48	27.8	11.4	<2.0	135.	5.1
6-30	F	21.5	8.3	2.4	<0.1	7.29	30.6				
7-1	S	20.1	8.1	4.1	<0.1	7.23	24.0	5.7	4.6	170.	40.5
7-3	M	20.0	8.2	2.9	<0.1						
7-4	T	20.0	7.6	2.1	<0.1	7.19	30.6	16.0	6.6	272.	15.8
7-6	Th	21.0	7.4	1.8	<0.1	7.38	28.8	19.1	4.3	254.	19.9
7-10	M	22.0	7.9	-	<0.1	7.10	25.9	7.7	4.6	123.	9.5
7-14	F	21.0	8.6	4.3	<0.1	7.36	22.3				
7-17	M	25.0	8.1	3.4	<0.1	7.19	24.3				
7-21	F	23.8	9.2	4.4	<0.1	7.28	21.6				
7-24	M	-	-	<1.5	<0.1	7.17	27.0	16.8	10.3	291.	6.0

Table 3 (continued)

				"Hydrocarbons"							
Date	Day	Temp. °C	D.O. mg O_2/l	Surf. mg/m^2	Col. mg/kg	pH	ALK mg $CaCO_3$/l	TP µg P/l	TSP µg P/l	Kj-N µg N/l	NIT µg N/l
7-28	F	26.0	9.0	<1.5	<0.1	7.38	28.5				
7-31	M	24.0	8.3	2.5	<0.1	7.12	25.0	16.5	2.0	296.	8.6
8-7	M	22.0	8.6	3.1	<0.1	7.20	24.3	9.1	<2.0	224.	6.0
8-16	W	22.0	10.5	4.0	<0.1	7.42	23.6	4.8	<2.0	176.	4.6
8-21	M	22.0	10.8	2.4	0.1	7.77	19.4	8.0	2.6	282.	3.3
8-28	M	23.1	9.2	2.2	<0.1	7.32	22.4	10.0	6.3	326.	3.2
9-4	M	21.9	8.4	<1.5	<0.1	7.40	23.5	15.4	2.9	376.	7.5
9-11	M	21.2	5.8	<1.5	<0.1	7.41	23.0	6.3	3.0	191.	6.5
9-18	M	20.2	9.4	<1.5	<0.1	7.08	23.4	14.5	<2.0	195.	7.0
9-25	M	18.0	9.4	<1.5	<0.1	7.07	18.9	8.0	2.3	384.	14.2

Table 4 - Water Quality Data

Dunham Bay: Station 4 - 1972

Date	Day	Temp. °C	D.O. mg O_2/l	"Hydrocarbons" Surf. mg/m^2	"Hydrocarbons" Col. mg/kg	pH	ALK mg $CaCO_3$/l	TP µg P/l	TSP µg P/l	Kj-N µg N/l	NIT µg N/l
3-30	Th	-	-	3.3	<0.1	6.66	34.5				
5-2	T	-	-	1.9	<0.1	6.91	26.3				
6-1	Th	20.0	7.8	1.9	<0.1	7.56	22.9	27.1	17.9	409.	1.6
6-9	F	18.0	8.9	1.7	<0.1	7.43	33.4				
6-12	M	17.0	9.0	<1.5	<0.1	7.37	59.0	62.4	10.3	804.	60.5
6-16	F	21.0	7.4	2.7	<0.1	7.48	46.0				
6-19	M	21.7	7.2	2.6	<0.1	7.47	49.3	21.6	7.4	348.	6.8
6-23	F	20.0	8.1	<1.5	<0.1	7.37	40.1				
6-26	M	18.1	5.4	1.9	<0.1	7.29	50.1	28.2	10.0	378.	22.0
6-30	F	24.2	5.7	4.0	<0.1	7.06	47.4				
7-1	S	22.0	4.5	22.2	<0.1	7.31	50.0	31.3	14.2	421.	134.0
7-3	M	26.0	4.8	3.5	0.1						
7-4	T	21.1	4.7	3.0	<0.1	7.03	44.8	29.6	12.5	419.	142.5
7-6	Th	22.0	5.1	1.0	<0.1	7.12	49.1	24.2	13.4	415.	28.0
7-10	M	22.0	6.2	7.8	<0.1	7.02	49.1	27.9	-	397.	2.2
7-14	F	25.2	6.2	15.0	<0.1	7.02	51.3				
7-17	M	29.0	5.5	2.6	<0.1	7.08	47.9				
7-21	F	27.0	5.5	2.4	<0.1	7.06	50.0				

Table 4 (continued)

				"Hydrocarbons"							
Date	Day	Temp. °C	D.O. mg O_2/l	Surf. mg/m^2	Col. mg/kg	pH	ALK mg $CaCO_3$/l	TP µg P/l	TSP µg P/l	Kj-N µg N/l	NIT µg N/l
7-24	M	-	-	<1.5	<0.1	7.15	55.4	40.7	16.0	506.	6.2
7-28	F	26.0	6.5	5.7	<0.1	7.28	53.3				
7-31	M	24.5	6.6	3.6	<0.1	7.55	68.9	33.6	16.0	559.	5.1
8-7	M	22.0	7.0	4.8	<0.1	7.36	61.4	30.2	13.7	452.	5.0
8-16	W	22.0	8.7	5.5	<0.1	7.56	39.2	39.0	14.8	490.	
8-21	M	24.9	8.9	5.6	0.1	7.32	56.7	21.1	17.7	436.	3.9
8-28	M	23.7	8.2	2.4	<0.1	7.08	23.0	8.8	<2.0	267.	8.9
9-4	M	22.9	10.2	4.0	<0.1	7.[illegible]	37.8	21.4	3.4	420.	5.6
9-11	M	19.0	7.8	<1.5	0.3	7.67	66.2	29.3	6.0	488.	5.2
9-18	M	20.5	9.2	1.7	<0.1	7.32	32.7	6.6	5.7	224.	9.8
9-25	M	16.5	7.0	<1.5	<0.1	7.57	57.2	30.4	25.2	420.	11.6

Table 5 - Water Quality Data

Echo Bay: Station 1 - 1972

				"Hydrocarbons"							
Date	Day	Temp. °C	D.O. mg O_2/l	Surf. mg/m^2	Col. mg/kg	pH	ALK mg $CaCO_3$/l	TP µg P/l	TSP µg P/l	Kj-N µg N/l	NIT µg N/l
6-1	Th	11.5	16.0	1.8	<0.1	7.47	25.1	11.1	2.8	122.	3.0
6-9	F										
6-12	M	14.0	10.8	2.0	<0.1	7.23	26.3				
6-16	F	16.5	8.5	5.9	<0.1	7.33	25.5				
6-19	M										
6-23	F	16.5	10.5	<1.5	<0.1	7.50	23.5				
6-26	M	18.0	8.0	4.1	<0.1	7.33	26.6	9.1	<2.0	163.	7.2
6-30	F	21.8	8.2	2.0	<0.1	7.37	23.4				
7-1	S	23.0	7.9	4.7	<0.1	7.23	24.3	6.3	<2.0	144.	11.7
7-3	M	23.2	8.5	4.7	<0.1						
7-4	T	19.9	8.2	3.7	<0.1	7.20	24.4	8.5	<2.0	271.	8.7
7-6	Th	19.8	7.9	2.2	0.1	7.31	25.2	6.0	<2.0	188.	5.9
7-10	M	21.0	7.4	3.1	<0.1	7.12	26.2	13.7	2.0	142.	13.3
7-14	F	22.5	7.8	3.1	<0.1	7.21	21.6				
7-17	M	24.9	7.8	2.1	<0.1	7.24	21.6				
7-24	M	25.3	8.2	2.2	<0.1	7.06	23.0	14.8	3.1	297.	7.9
7-28	F	25.0	8.2	<1.5	<0.1	7.33	24.3				
7-31	M	24.5	8.8	<1.5	<0.1	7.04	20.3	5.4	2.3	212.	4.7

Table 5 (continued)

Date	Day	Temp. °C	D.O. mg O_2/l	"Hydrocarbons" Surf. mg/m^2	"Hydrocarbons" Col. mg/kg	pH	ALK mg $CaCO_3$/l	TP µg P/l	TSP µg P/l	Kj-N µg N/l	NIT µg N/l
8-7	M	22.0	8.0	3.6	<0.1	7.31	16.9	7.1	2.8	261.	8.9
8-16	W	22.0	10.4	4.7	<0.1	7.45	25.0	7.1	6.6	276.	3.2
8-21	M	23.0	10.2	6.5	<0.1	7.12	22.7	14.0	2.3	362.	12.5
8-28	M	23.0	8.3	2.7	<0.1	7.46	22.7	16.8	2.0	704.	8.7
9-4	M	22.0	8.2	2.1	<0.1	-	-	8.5	4.6	218.	7.4
9-11	M	21.0	8.2	3.8	<0.1	7.23	22.1	21.1	<2.0	256.	3.7
9-18	M	20.2	9.3	<1.5	<0.1	7.04	22.3	9.7	-	260.	9.6
9-25	M	17.5	9.6	<1.5	<0.1	7.29	23.1	7.4	6.6	168.	9.8

Table 6 - Water Quality Data

Echo Bay: Station 2 - 1972

				"Hydrocarbons"							
Date	Day	Temp. °C	D.O. mg O_2/l	Surf. mg/m^2	Col. mg/kg	pH	ALK mg $CaCO_3$/l	TP µg P/l	TSP µg P/l	Kj-N µg N/l	NIT µg N/l
6-1	Th										
6-9	F										
6-12	M										
6-16	F	18.0	9.3	2.6	<0.1	7.35	25.1				
6-19	M	16.8	9.2	6.2	<0.1	7.40	25.0	5.1	3.4	174.	7.8
6-23	F										
6-26	M	18.8	8.1	1.9	<0.1	7.46	23.6	11.4	<2.0	142.	6.0
6-30	F	21.5	7.8	2.4	<0.1	7.34	23.0				
7-1	S	20.0	7.9	1.6	<0.1	7.33	23.0	9.1	3.4	206.	44.0
7-3	M	21.0	8.0								
7-4	T	19.0	8.5	3.0	<0.1	7.30	22.8	7.7	3.4	203.	8.2
7-6	Th	19.8	8.6	<1.5	<0.1	7.55	23.6	4.6	3.1	198.	4.6
7-10	M	20.0	7.8	5.7	<0.1	7.21	22.5	9.1	6.6	102.	10.2
7-14	F	22.5	8.2	1.6	<0.1	7.18	23.0				
7-17	M	24.0	8.1	2.2	<0.1	7.23	21.6				
7-24	M	25.0	9.1	2.6	<0.1	7.15	20.9	12.5	11.7	224.	5.3
7-28	F	25.0	8.6	<1.5	<0.1	7.42	24.3				
7-31	M	24.5	9.1	2.6	<0.1	7.16	16.9	12.8	<2.0	842.	5.1

Table 6 (continued)

				"Hydrocarbons"							
Date	Day	Temp. °C	D.O. mg O_2/l	Surf. mg/m^2	Col. mg/kg	pH	ALK mg $CaCO_3$/l	TP µg P/l	TSP µg P/l	Kj-N µg N/l	NIT µg N/l
8-7	M	22.0	8.2	4.0	<0.1	7.36	32.0	6.0	<2.0	210.	6.0
8-16	W	22.8	10.1	7.3	<0.1	7.62	22.3	10.3	9.4	263.	2.6
8-21	M	22.5	10.2	7.1	<0.1	7.12	22.1	6.3	<2.0	180.	5.0
8-28	M	23.0	8.6	2.1	<0.1	7.57	22.1	12.5	<2.0	495.	7.4
9-4	M	22.1	9.2	<1.5	<0.1	7.40	22.3	4.0	<2.0	294.	5.7
9-11	M	20.9	8.8	2.6	<0.1	7.38	22.3	9.7	6.3	456.	4.5
9-18	M	19.9	9.2	1.7	<0.1	-	-	8.0	-	376.	8.7
9-25	M	17.0	9.1	<1.5	0.1	7.40	21.7	9.4	-	234.	14.5

Table 7 - Water Quality Data

Smith Bay: Station 1 - 1972

Date	Day	Temp. °C	D.O. mg O_2/l	"Hydrocarbons" Surf. mg/m^2	"Hydrocarbons" Col. mg/kg	pH	ALK mg $CaCO_3$/l
6-1	Th						
6-9	F	14.5	9.6	3.2	<0.1	7.66	32.8
6-16	F	15.3	9.2	2.6	<0.1	7.37	28.1
6-19	M						
6-23	F	19.0	9.2	2.0	<0.1		
6-26	M						
6-29	Th	21.0	7.7	4.3	<0.1	7.45	18.5
7-1	S	25.9	8.4	1.9	<0.1	7.38	27.8
7-13	Th	22.5	8.3	7.9	<0.1	7.36	23.0
7-27	Th	25.2	9.0	2.7	<0.1	7.41	24.3
8-1	T	23.5	9.1	3.2	<0.1	7.12	23.0
8-8	T	23.0	9.8	<1.5	<0.1	7.56	28.4
8-14	M	21.0	10.8	<1.5	<0.1	7.38	20.9
8-29	T	22.2	9.2	1.6	<0.1		
9-4	M	21.2	8.8	<1.5	<0.1	7.57	25.4
9-11	M	20.0	9.0	<1.5	<0.1		
9-18	M	20.1	9.2	<1.5	<0.1		
9-25	M	17.1	10.2	2.5	<0.1		

Table 8 - Water Quality Data

Smith Bay: Station 2 - 1972

				"Hydrocarbons"			
Date	Day	Temp. °C	D.O. mg O_2/l	Surf. mg/m^2	Col. mg/kg	pH	ALK mg $CaCO_3$/l
6-1	Th	-	-	1.8	<0.1	7.73	26.3
6-9	F	15.0	9.5	1.8	-	7.60	24.9
6-16	F	15.2	9.7	2.5	-	7.37	25.3
6-19	M	17.8	9.2	5.9	<0.1	7.46	24.9
6-23	F						
6-26	M	18.5	7.6	5.7	<0.1	7.55	24.0
6-29	Th	20.0	7.9	2.1	<0.1	7.22	25.8
7-1	S	21.0	8.4	4.1	<0.1	7.28	23.7
7-13	Th	22.5	8.4	12.0	<0.1	7.45	22.3
7-27	Th	25.0	9.0	<1.5	<0.1	7.38	25.0
8-1	T	23.4	9.4	2.8	<0.1	7.41	23.6
8-8	T	23.0	10.1	<1.5	<0.1	7.47	24.3
8-14	M	21.0	10.0	<1.5	<0.1	7.59	23.0
8-29	T	21.5	9.2	1.6	<0.1		
9-4	M	21.9	8.9	<1.5	<0.1	7.50	23.0
9-11	M	19.0	8.6	3.6	<0.1		
9-18	M	19.5	9.7	1.9	<0.1		
9-25	M	17.2	9.8	1.5	<0.1		

Table 9

Recovery Runs

Bulk (Column) Recoveries

Water	Oil Added (mg/kg)	Solvent	% Recovery
Smith Bay	0.102	CCl_4	65.6
Smith Bay	0.107	CCl_4	51.7
Smith Bay	0.126	Freon TF	61.0
Distilled	0.124	Freon TF	72.4
Smith Bay	0.308	CCl_4	90.3
Smith Bay	0.312	CCl_4	85.9
Smith Bay	0.326	Freon TF	74.3
Distilled	0.305	Freon TF	74.6
Smith Bay	0.497	CCl_4	83.0
Smith Bay	0.520	CCl_4	93.5
Smith Bay	0.534	Freon TF	91.2
Distilled	0.479	Freon TF	75.3

Table 9 (continued)

Recovery Runs

Surface Recoveries*

Water	Oil Added (mg/m^2)	Solvent	% Recovery		
			1st$^+$	2nd$^+$	Total
Smith Bay	9.87	CCl_4	22.8	14.7	37.5
		CCl_4	63.7	18.1	81.8
		CCl_4	6.9	25.0	31.9
Smith Bay	19.75	CCl_4	46.7	57.3	104.0
Smith Bay	29.60	CCl_4	36.3	21.1	57.4

*Florisil Treated; $^+$Replicate samplings of the same surface

Surface concentrations of Florisil-treated "hydrocarbons" were generally between 1.0 and 5.0 mg/m^2. The reliability of these numbers are more in question than those of the water column largely due to the sampling problems discussed. From Table 9, recovery of "hydrocarbon" film is no better than one-third. Caution must, however, be exercised in applying table numbers because of the additional difficulty of evaluating a surface sampler. The evaluation runs were made in a 300 gal. metal tank having a surface area of only 1.1 meters. The sampling pot, therefore, disturbed the film in passage through the surface with a smaller likelihood of reformation than would be the case for a very large surface area (as is the case with the lake sampling). Additionally, there was the initial difficulty of creating a uniform film in the test tank. The oil was added by syringe and each drop was touched off at the water surface. Approximately fifteen minutes were allowed for the films to form, and this process could be followed when the surface was viewed obliquely. In all runs, the film formed was not uniform. At the lowest oil levels, the film was noticeably patchy and there did not appear to be continued dispersal (although this was not confirmed). All values in Table 9 are recoveries minus background. Triplicate surface samplings at each station in Echo Bay gave deviations of 2.5 ± 37% and 1.0 ± 35% for the total extract, and 1.3 ± 7.1% and 0.9 ± 15%, respectively for the Florisil-treated extracts, all in terms of mg "hydrocarbon" per m^2.

DISCUSSION

The results of the present study indicate the absence of any gross pollution from outboard motor exhaust in Dunham, Echo and Smith Bays of Lake George, New York. Levels of Florisil-treated extracts in these bays are plotted in Figs. 6-9. An increase of extractable materials is indicated in all the bays for the July-August period when boating activity would be expected to be maximal. Assuming that all of the extractables were outboard motor exhaust, and that only one-third of the "hydrocarbon" is being recovered, the level of 5 mg/m^2 would still be well below that found to cause a "barely visible" film. Studies conducted at the EPA Edison Laboratory show that a concentration of 38 mg/m^2 of oil, under ideal conditions, viz., a bright overcast sky, a 45° viewing angle, a smooth surface over a dark colored bottom, and an adjacent, contrasting area without any film, can result in a barely visible film.

Sampling personnel reported no visible films during the course of the 1972 boating season in the study bays. This may be due to the time of sampling, which generally occurred from late morning to afternoon. However, films have been reported by campers around islands in Lake George. These sightings have been made at dawn when conditions for viewing films approach "ideal", i.e. the air tends to be still, the surface calm, and the lighting muted and uniform.

No appreciable differences were found for the different sampling stations in surface "hydrocarbon". Station 4 of Dunham Bay, which is actually located in mid-stream of Dunham Bay Creek, is immediately adjacent to a small marina. While the highest surface values for the 1972 boating season

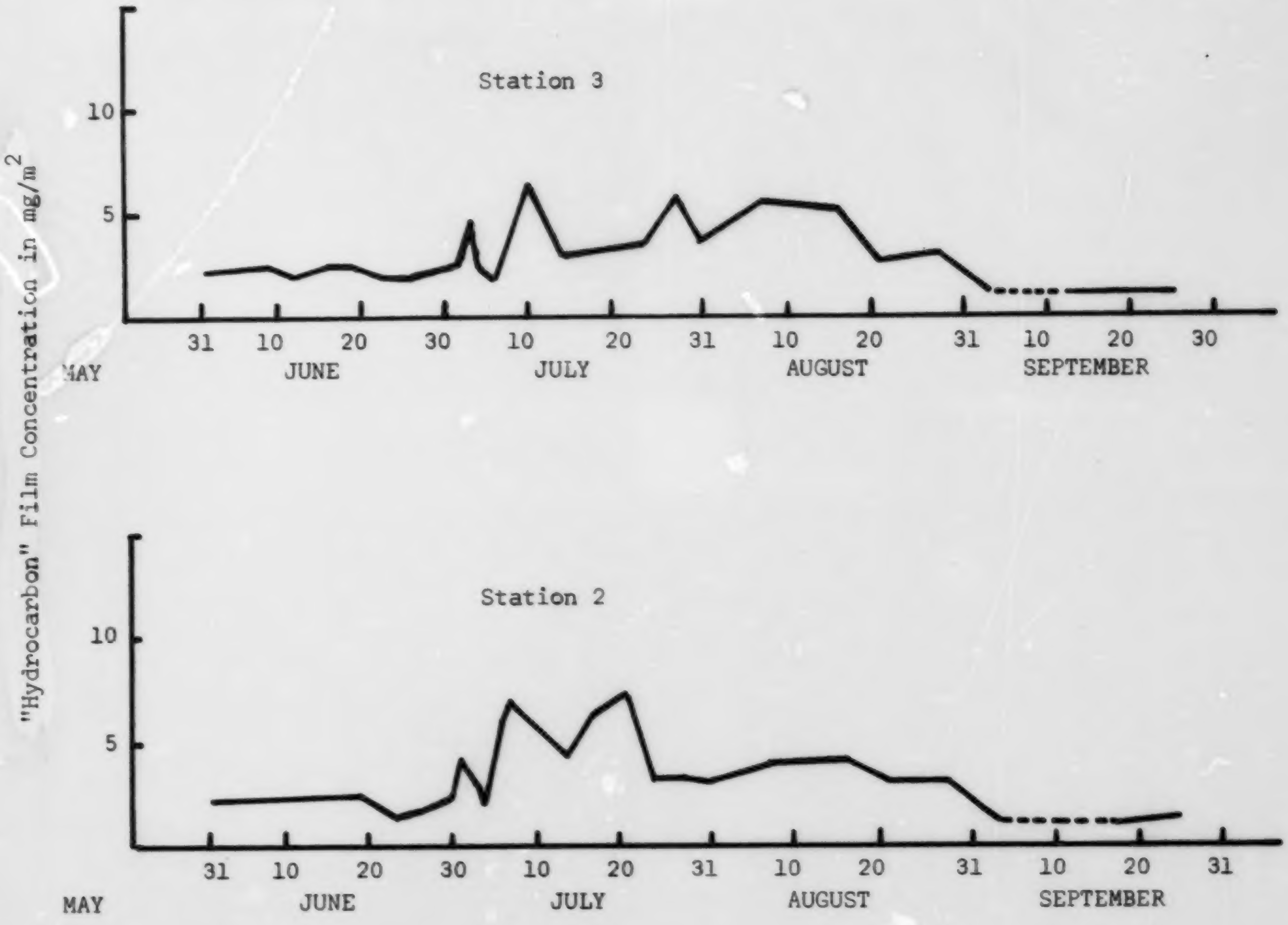

Figure 6 - Surface Film Levels of "Hydrocarbons" in Dunham Bay

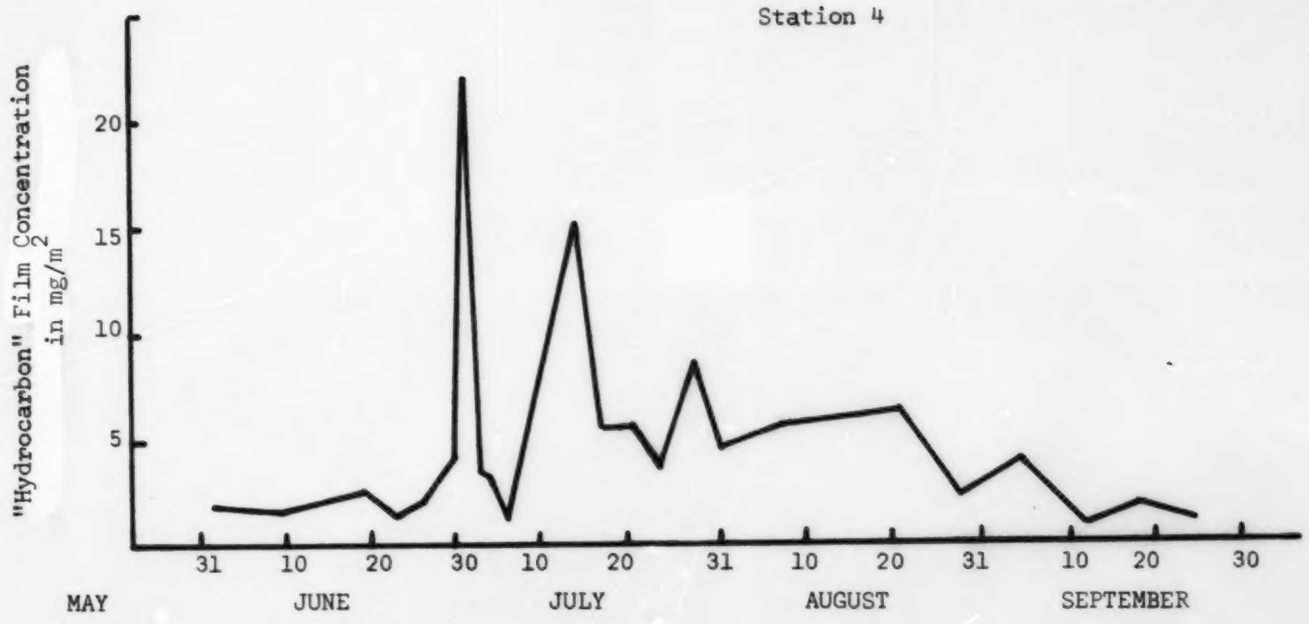

Figure 7 - Surface Film Levels of "Hydrocarbons" in Dunham Bay

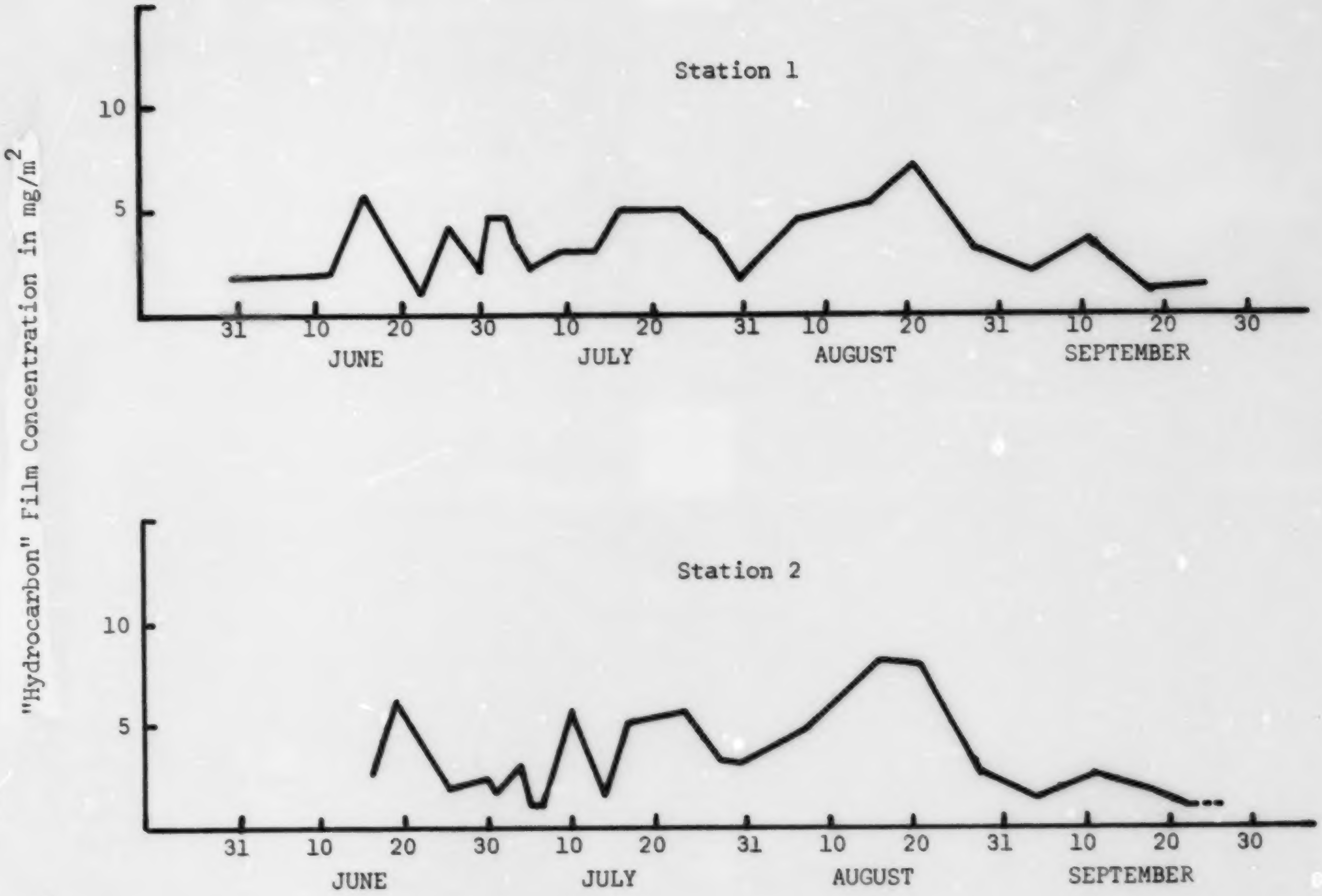

Figure 8 - Surface Film Levels of "Hydrocarbons" in Echo Bay

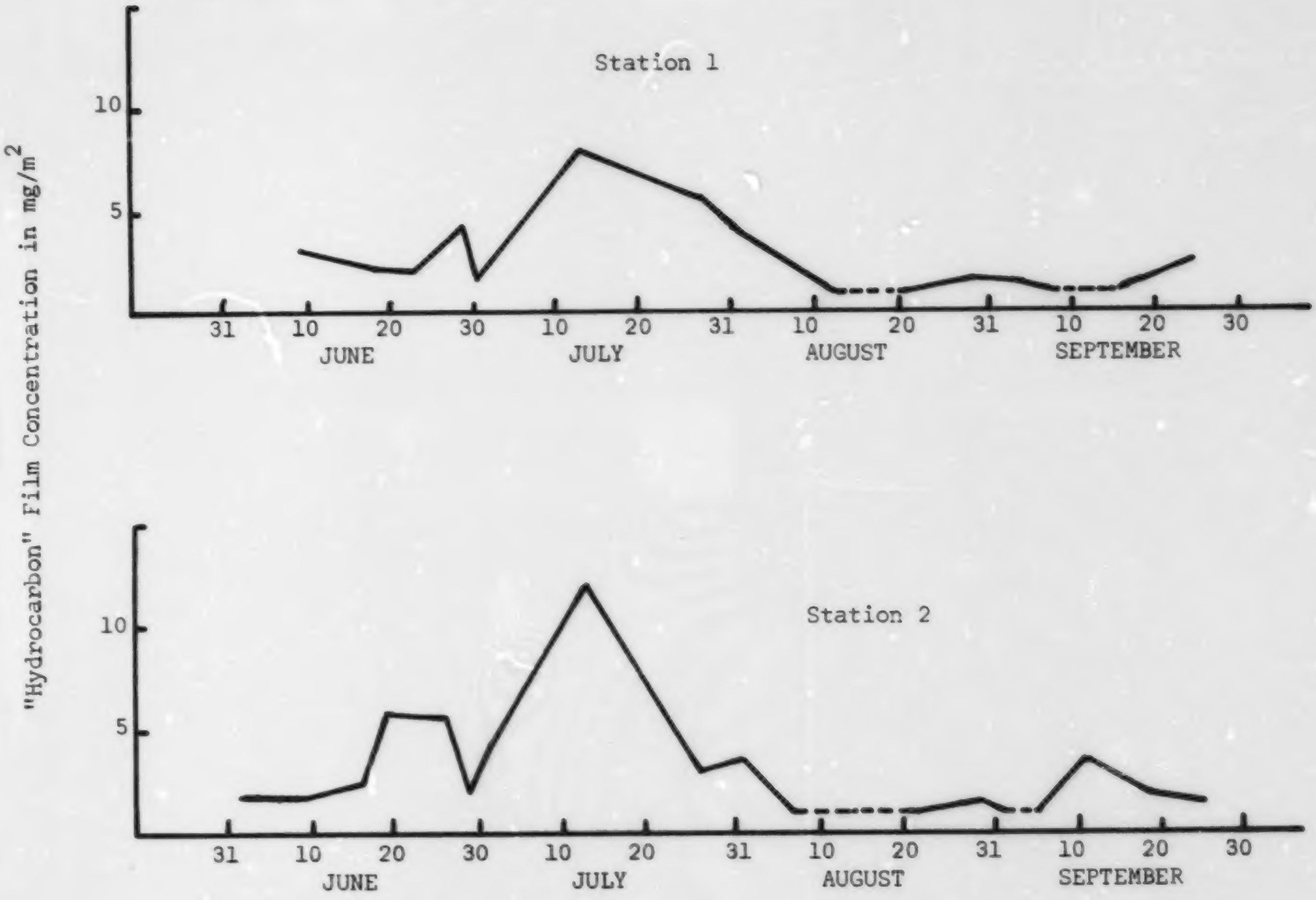

Figure 9 - Surface Film Levels of "Hydrocarbons" in Smith Bay

were found at this station, season-wise concentrations are of the same order as found in Station 3 which is located approximately in the middle of the bay itself.

It should be stressed again that the IR procedure is non-differentiating for organic material. Any compounds consisting of CH_2 and CH_3 groups which are extractable from the acidified solution, with the solvents used, can contribute to the sample absorbance. Passage through the Florisil column will reduce the polar components and tend to isolate the non-polar, including aliphatic, components. Because of the low level of "hydrocarbon" found, the importance of removing background materials, e.g. humics, lipids, proteinaceous substances, and pigments, is great. While Florisil will retain much of this material, it can also retain oxidized oil components resulting from decomposition processes, photochemical reactions and the operation of the outboard engine.

A possible complicating factor is the interaction of fulvic acids with hydrophobic substances such as alkanes to form soluble complexes as reported by Ogner and Schnitzer (53). These workers found that the alkanes could not be extracted with solvents unless the complex was first methylated. Dunham Bay Creek drains a large wetlands area and is highly colored. Values reported by Kobayashi (38) indicate that humic concentrations are at least four times higher in the creek than they are in the bay proper. Whether humic substances, such as the fulvic acids, actually do retain "hydrocarbons", however, is speculative.

The analytical procedure cannot distinguish between hydrocarbon compounds arising from outboard engine use, and those which occur naturally in the environment. While the latter group would represent a positive interference, there is, as yet, no quantitative data to assess its importance.

SECTION V - MICROBIOLOGICAL STUDIES

Decomposition Studies

Seasonal characterization of the relative quantity and activity of the heterotrophic microflora in Dunham, Echo, and Smith Bays was made.

The work is described in the following sections:

a) concentration
b) laboratory plate investigations
c) pure culture studies
d) sediment storage
e) oxygen uptake
f) radioisotope uptake

Samples for microbiological analysis have been taken from surface water, half depth in the water column, and from the sediments.

Sampling Methods

For surface water cell enumeration, 20 ml surface water samples were collected. This was done by suspending horizontally an empty, covered, sterile 20 ml test tube at the water surface. The cover was then removed, and the tube allowed to fill with water from a depth no greater than three quarters of an inch. The tube was then re-covered with its cap and kept on ice to await lab analysis.

For analysis, a 1 ml aliquot was withdrawn from the lake sample and put into 9 ml of sterile nutrient broth. From this tube, six serial dilutions were made, in broth, for MPN method of enumeration. For plate counts on both nutrient and hydrocarbon agars, a 0.6 ml aliquot was removed from each serial dilution tube: 0.3 ml plated on nutrient agar, 0.3 ml on hydrocarbon agar.

A six-liter VanDorn water sampler was used to obtain water column samples from mid-depth at each station. From this large sample, four 1 ml aliquots were withdrawn and each of these used to inoculate a sterile 9 ml nutrient broth tube. These inoculated broth tubes (four per station) were kept on ice awaiting lab analysis.

For analysis, six serial dilutions in broth were done from each inoculated (at time of sampling) tube. From each dilution tube a 0.6 ml aliquot was removed: 0.3 ml plated on nutrient agar, 0.3 ml on hydrocarbon agar.

Sediment was collected in one-liter quantities using an Eckman dredge. These samples were placed in sterile one-liter plastic containers, covered, and placed on ice.

For oxygen uptake studies, samples of sediment were removed from these containers in quantities of about 1.2 g for each respirometer flask.

Samples were collected and prepared for radioisotope analysis in the following manner. Water samples from Dunham and Echo Bays were collected in a six-liter VanDorn sampler and placed in sterile, four-liter plastic containers. Samples were kept on ice for transportation to the laboratory and stored there at 4°C prior to analysis.

For each assay, one liter of water was membrane filtered in order to concentrate the microflora by approximately one hundred-fold. The rate of incorporation of C^{14}-glucose was then determined for these microbial concentrates.

A 0.3 ml aliquot was withdrawn from the four-liter sample for enumerating the organisms by a plate count. Plate counts were done in duplicate.

An Eckman dredge was used to obtain sediment samples, which were placed in sterile, one-liter, plastic containers, and stored at 4°C until analyzed. The sediment suspension was diluted to twice its volume and 7.4 ml withdrawn for each glucose incorporation assay. The rate of incorporation was correlated with the amount of combustible organic matter present in the sediment.

Concentration of Heterotrophic Microorganisms

Throughout the study, water samples have been analyzed for the concentration of heterotrophic microbes by means of the MPN technique, by plate counts on nutrient agar, and by plate counts on petroleum agar. Water samples were always analyzed within four hours of collection and kept on ice in the interim.

Petroleum agar was prepared by blending 1/2 gram SAE 40 motor oil (Mobil Oil Outboard Super), 20 mg Difco yeast extract, and 15 grams of Difco agar in one-liter distilled water. The emulsion was maintained during autoclaving.

Incubations at various temperatures have been made with samples taken from the water column showing maximum rate of colony development at 30°C with a lower limit of 10°C at which no colonies develop even after a 3-4 day period of incubation. Normally the plates were incubated from 24-48 hours.

In the following tables the cell concentration data are presented along with the critical physical parameters of depth of sample (for water column, temperature, and dissolved oxygen concentration, in that order). Counts on petroleum agar are underlined. (Tables 10-12) Each count represents an average of duplicate analyses. The data for Echo Bay does not begin to any extent until late in June of 1972 when systematic sampling began. At the same time dock building at Smith Bay with its obvious disturbances rendered its inclusion relatively useless with respect to study of microflora.

Table 10

Cell Concentration in the Water Column

(petroleum agar underlined)

Dates	Dunham Bay			Echo Bay		Smith Bay
	Station 2	Station 3	Station 4	Station 1	Station 2	Station 1
10/20/71	10^3/ml * 1.5m **16.9°C -	10^3/ml 3.0m 16.2°C -	10^3/ml 0.75m 14.2°C -			
11/9/71	10^3/ml 1.5m 8.8°C -	10^3/ml 3.0m 9.2°C -	10^3/ml 0.75m 2.9°C -			
12/1/71			10^4/ml 0.75m 1.5°C -	10^2/ml 0.75m		
3/30/72		10^3/ml 3.5m - -	10^4/ml 0.5m - -			
5/2/72	10^2/ml 1.5m 5.0°C ***19.5mg/l	10^3/ml 3.0m 4.0°C 3.8mg/l	10^2/ml 0.75m 12.0°C 16.4mg/l			
6/1/72	10^2/ml 1.5m - -	10^2/ml 3.0m - -	10^3/ml 0.75m - -			
6/12/72	10^2/ml $\underline{0/\mathrm{ml}}$ 1.5m 13.0°C 10.2mg/l	10^2/ml $\underline{4\times10^{6}/\mathrm{ml}}$ 3.0m 13.0°C 10.4mg/l	10^3/ml $\underline{5\times10^{6}/\mathrm{ml}}$ 0.75m 16.0°C 8.5mg/l			10^4/ml

*depth of water sample throughout

**water temperature throughout

***dissolved oxygen concentration throughout

Table 10 (continued)

Dates	Dunham Bay			Echo Bay		Smith Bay
	Station 2	Station 3	Station 4	Station 1	Station 2	Station 1
6/19/72	10^2/ml 0/ml 1.5m 15.0°C 10.0mg/l	10^2/ml $3x10^0$/ml 3.0m 15.0°C 9.8mg/l	10^3/ml 10^1/ml 0.75m 20.0°C 7.4mg/l		10^3/ml 1.5m 15.8°C 9.4mg/l	
6/26/72	10^3/ml $1x10^0$/ml 1.5m 16.9°C 8.0mg/l	10^2/ml 0/ml 3.0m 16.5°C 8.0mg/l	10^4/ml $1.2x10^1$/ml 0.75m 17.5°C 5.3mg/l	10^3/ml $3x10^0$/ml 0.75m 17.5°C 7.9mg/l	10^3/ml 0/ml 1.0m 18.0°C 8.1mg/l	10^4/ml $5x10^0$/ml
7/1/72	10^3/ml 0/ml 1.5m 19.9°C 8.2mg/l	10^3/ml 0/ml 3.0m 19.0°C 8.2mg/l	10^4/ml $3x10^2$/ml 0.75m 22.0°C 4.1mg/l	10^3/ml $1x10^1$/ml 0.75m 23.0°C 7.7mg/l	10^2/ml 0/ml 1.0m 19.1°C 7.9mg/l	
7/3/72	10^0/ml 1.5m 20.0°C 8.2mg/l	10^3/ml 3.0m 18.0°C 8.6mg/l	10^3/ml 0.75m 25.0°C 5.8mg/l	10^4/ml 0.75m 23.0°C 7.7mg/l	10^4/ml 1.0m 20.1°C 8.1mg/l	
7/4/72	10^3/ml - 1.5m 20.0°C 7.4mg/l	10^3/ml - 3.0m 19.0°C 7.9mg/l	10^3/ml 18/ml 0.75m 20.5°C 4.7mg/l	10^3/ml 50/ml 0.75m 19.5°C 7.7mg/l	10^3/ml - 1.5m 19.0°C 8.4mg/l	
7/6/72	10^3/ml - 1.5m 20.1°C 7.7mg/l	10^2/ml - 3.0m 18.9°C 8.1mg/l	10^5/ml 10^2/ml 0.75m 20.0°C 4.9mg/l	10^2/ml - 0.75m 19.0°C 7.6mg/l	10^3/ml - 1.5m 19.2°C 7.8mg/l	
7/10/72	10^3/ml 1.5m 21.6°C 7.9mg/l	10^2/ml 3.0m 19.9°C 7.8mg/l	10^4/ml 0.75m 22.0°C 6.2mg/l	10^4/ml 0.75m 20.9°C 7.4mg/l	10^4/ml 1.0m 20.9°C 7.7mg/l	
7/24/72	10^2/ml - -	10^2/ml - -	10^3/ml - -	10^4/ml 25.2°C 8.4mg/l	10^3/ml 25.0°C 9.0mg/l	

Table 10 (continued)

Dates	Dunham Bay			Echo Bay		Smith Bay
	Station 2	Station 3	Station 4	Station 1	Station 2	Station 1
7/31/72	10^4/ml - -	10^4/ml - -	10^4/ml - -	10^3/ml - -	10^3/ml - -	
8/7/72	10^4/ml - -	10^4/ml - -	10^5/ml - -	10^3/ml - -	10^4/ml - -	
8/16/72	10^4/ml 22.0°C 10.5mg/l	10^3/ml 21.5°C 9.8mg/l	10^4/ml 21.0°C 9.4mg/l	10^4/ml 21.0°C 9.9mg/l	10^4/ml 22.0°C 10.2mg/l	
8/21/72	10^4/ml 21.8°C 9.8mg/l	10^3/ml 22.0°C 10.1mg/l	10^4/ml 24.4°C 8.7mg/l	10^5/ml 22.2°C 9.8mg/l	10^6/ml 22.0°C 10.0mg/l	
8/28/72	10^4/ml 23.1°C 9.2mg/l	10^3/ml 23.0°C 9.1mg/l	10^3/ml 23.6°C 8.3mg/l	10^4/ml 23.1°C 8.2mg/l	10^3/ml 22.8°C 8.6mg/l	
9/4/72	10^4/ml 21.9°C 8.4mg/l	10^3/ml 21.7°C 8.3mg/l	10^3/ml 23.0°C 9.7mg/l	10^4/ml 22.2°C 8.9mg/l	10^4/ml 22.1°C 8.1mg/l	
9/11/72	10^2/ml 20.0°C 5.2mg/l	10^3/ml 20.9°C 8.2mg/l	10^4/ml 18.0°C 7.2mg/l	10^4/ml 21.0°C 8.2mg/l	10^3/ml 20.3°C 8.0mg/l	
9/18/72	10^3/ml 20.0°C 9.3mg/l	10^4/ml 19.8°C 9.4mg/l	10^3/ml 20.0°C 8.4mg/l	10^3/ml 20.1°C 9.6mg/l	10^3/ml 19.9°C 9.9mg/l	
9/25/72	10^3/ml - -	10^3/ml - -	10^4/ml - -	10^3/ml - -	10^2/ml - -	

Table 11

Cell Concentration in Surface Water

(petroleum agar underlined)

Dates	Dunham Bay			Echo Bay	
	Station 2	Station 3	Station 4	Station 1	Station 2
6/12/72		10^{1}/ml 0/ml *14.0°C **11.0mg/l	10^{2}/ml 0/ml 14.0°C 10.4mg/l		
6/26/72	10^{2}/ml 17.2°C 7.9mg/l	10^{1}/ml 17.8°C 7.9mg/l	10^{2}/ml 18.1°C 5.4mg/l	10^{1}/ml 18.0°C 8.0mg/l	10^{1}/ml 18.8°C 8.1mg/l
7/1/72	10^{2}/ml 20.1°C 8.1mg/l	10^{3}/ml 20.9°C 7.9mg/l	10^{4}/ml 22.0°C 4.5mg/l	10^{3}/ml 23.0°C 7.9mg/l	0/ml 20.0°C 7.9mg/l
7/3/72	10^{1}/ml 20.0°C 8.4mg/l	10^{2}/ml 20.5°C 7.7mg/l	10^{2}/ml 26.0°C 4.8mg/l	10^{2}/ml 23.2°C 8.5mg/l	None 21.0°C 8.0mg/l
7/4/72	10^{3}/ml 20.0°C 7.6mg/l	10^{3}/ml 20.0°C 7.9mg/l	10^{4}/ml 21.1°C 4.7mg/l	10^{4}/ml 19.9°C 8.2mg/l	10^{3}/ml 19.0°C 8.5mg/l
7/6/72	10^{1}/ml 21.0°C 7.4mg/l	10^{0}/ml 20.0°C 7.9mg/l	10^{2}/ml 22.0°C 5.1mg/l	10^{2}/ml 19.8°C 7.9mg/l	10^{1}/ml 19.8°C 8.6mg/l
7/10/72	3×10^{1}/ml 3×10^{0}/ml 22.0°C 7.9mg/l	10^{1}/ml 20.1°C 8.2mg/l	5.2×10^{1}/ml 2×10^{1}/ml 22.0°C 6.2mg/l	3×10^{2}/ml 21.0°C 7.4mg/l	10^{1}/ml 20.0°C 7.8mg/l
7/24/72	5×10^{1}/ml 3×10^{2}/ml - -	10^{2}/ml 10^{3}/ml - -	10^{2}/ml 10^{3}/ml - -	10^{3}/ml 10^{4}/ml 25.3°C 8.2mg/l	10^{2}/ml 10^{4}/ml 25.0°C 9.1mg/l

*temperature of water sample throughout
**dissolved oxygen concentration throughout

Table 11 (continued)

	Dunham Bay			Echo Bay	
Dates	Station 2	Station 3	Station 4	Station 1	Station 2
7/31/72	10^2/ml 10^1/ml - -	10^2/ml 10^0/ml - -	10^1/ml 10^1/ml - -	10^1/ml 10^1/ml - -	10^1/ml 10^1/ml - -
8/7/72	10^2/ml - -	10^2/ml - -	10^4/ml - -	10^2/ml - -	10^2/ml - -
8/16/72	10^2/ml 3×10^0/ml 22.0°C 10.5mg/l	10^2/ml 22.0°C 9.8mg/l	10^2/ml 10^1/ml 22.0°C 8.7mg/l	10^2/ml 22.0°C 10.4mg/l	10^2/ml 22.8°C 10.1mg/l
8/21/72	10^2/ml 4×10^0/ml 22.0°C 10.8mg/l	10^2/ml 0/ml 22.7°C 11.0mg/l	10^4/ml 10^1/ml 24.9°C 8.9mg/l	10^2/ml 3×10^0/ml 23.0°C 10.2mg/l	10^1/ml 0/ml 22.5°C 10.2mg/l
8/28/72	10^2/ml 0/ml 23.1°C 9.2mg/l	10^2/ml 0/ml 23.2°C 9.2mg/l	10^2/ml 3×10^0/ml 23.7°C 8.2mg/l	10^2/ml 0/ml 23.0°C 8.3mg/l	10^2/ml 0/ml 23.0°C 8.6mg/l
9/4/72	10^3/ml 3×10^0/ml 22.0°C 8.5mg/l	10^2/ml 0/ml 21.9°C 8.4mg/l	10^4/ml 4×10^1/ml 22.9°C 10.2mg/l	10^2/ml 0/ml 22.1°C 9.2mg/l	10^2/ml 0/ml 22.0°C 8.2mg/l
9/11/72	10^1/ml 21.2°C 5.8mg/l	10^2/ml 21.0°C 8.9mg/l	10^2/ml 19.0°C 7.8mg/l	10^2/ml 21.0°C 8.2mg/l	0/ml 20.9°C 8.8mg/l
9/18/72	10^2/ml 10^2/ml 20.2°C 9.4mg/l	10^1/ml 10^2/ml 20.2°C 9.6mg/l	10^3/ml 10^2/ml 20.5°C 9.2mg/l	10^2/ml 10^2/ml 20.2°C 9.3mg/l	10^1/ml 10^2/ml 19.9°C 9.2mg/l
9/25/72	10^3/ml 10^3/ml - -	10^2/ml 10^2/ml - -	10^4/ml 10^5/ml - -	10^2/ml 10^3/ml - -	10^2/ml 10^1/ml - -

Table 12

Cell Concentration in Culture Flasks (x 10^2/ml)

(petroleum agar underlined)

Run	Flask	Hours into Incubation				
		0	4	10	22	24
1 10/17/72	A	0.4*	0	0	0	0
		0.3**	0	0	1.0	0
	B	6.7	0	0	0	0
		4.8	0	0	0	0
	C	31.0	0	0	0	0
		20.0	0.1	0	0	0
	D	0.6	0	0	0	0
		0.1	0	0	0	0

Run	Flask	Hours into Incubation				
		0	4	8	17	21
2 11/25/72	A	0.1	0	2.0	0	0
		0	0	0	0	0
	B	0.1	0	0	0	0
		0	0	0	0	0
	C	0	0	0	30.0	0
	D	0.4	4.0	5.0	1.0	0
		0.4	50.0	0	1.0	0

---

*Counts made on nutrient agar

**Counts made on petroleum agar

Table 12 (continued)

		Hours into Incubation				
Run	Flask	0	3.25	6.5	12.5	14.5
3 11/30/72	A	50.0	1.0	0	0	0.1
		30.0	0	0	0	0
	B	160.0	0	0	0.3	0
		30.0	0	0	0	0
	C	100.0	0	3.0	0	0
		4.0	0	0.1	0	0
	D	150.0	0	0	0	0
		30.0	0	0	0	0

Laboratory Plate Investigations

During enumeration of surface cell population, when plating water samples on both nutrient agar and on petroleum agar, it was frequently seen that more colonies appeared on the petroleum than on the nutrient agar for a given water sample. Those on the petroleum agar were smaller than those on nutrient agar. Colonies on nutrient agar were obviously from differing genera, whereas petroleum metabolizers were identical in appearance, implying that they were of the same genus. See, for example, the data in Table 11 for the dates 7/24/72, 9/18/72, and 9/25/72. (This phenomenon continues to be seen in lake studies as well as in batch cultures which are described later.)

Since these samples were identical, it would seem that, at best, the counts on the two agars should be identical, and assuming motor oil to be far more difficult for microbes to metabolize, it seems reasonable that the petroleum agar populations should be smaller. Two explanations were offered:

1. The petroleum metabolizers are selective for the motor oil and cannot thrive on nutrient agar.
2. Certain (one or more) of those colonial species found on the nutrient agar produce some kind of substance toxic to the petroleum microbe, such that the two are unable to co-exist on the same nutrient agar plate.

These possibilities were investigated by various culture combinations on the two agars.

First, the petroleum metabolizer was plated alone on the nutrient agar. Growth was abundant in 36 to 48 hours. Colonies were larger but only slightly more colored than when grown on petroleum agar (on petroleum agar, colonies are opaque - white; on nutrient agar, they appear off-white). This observation seemed to rule out the former explanation above.

To test the second hypothesis, several systems were set up. Two sets of plates were inoculated for each of the original lake sample plates: one set was nutrient agar and the other, petroleum agar.

On each plate one colony was streaked from the nutrient agar plate with one colony from the petroleum agar plate. This was done with each phenotypically different colony on the nutrient agar. The colonies from the petroleum agar were assumed identical. (See Fig. 10 for clarification)

The petroleum oxidizers grew on both agars in the presence of any one of the other original nutrient agar colonies. The original nutrient agar cells grew on the nutrient agar copiously and one was found to also grow on the petroleum agar, along with the original petroleum oxidizer. This colony, when grown on nutrient agar, was bright orange, whereas, while growing on petroleum agar was off-white in color. Therefore, it was inferred that perhaps those colonies found on the original petroleum agar were indeed of various genera but simply appeared similar on petroleum agar.

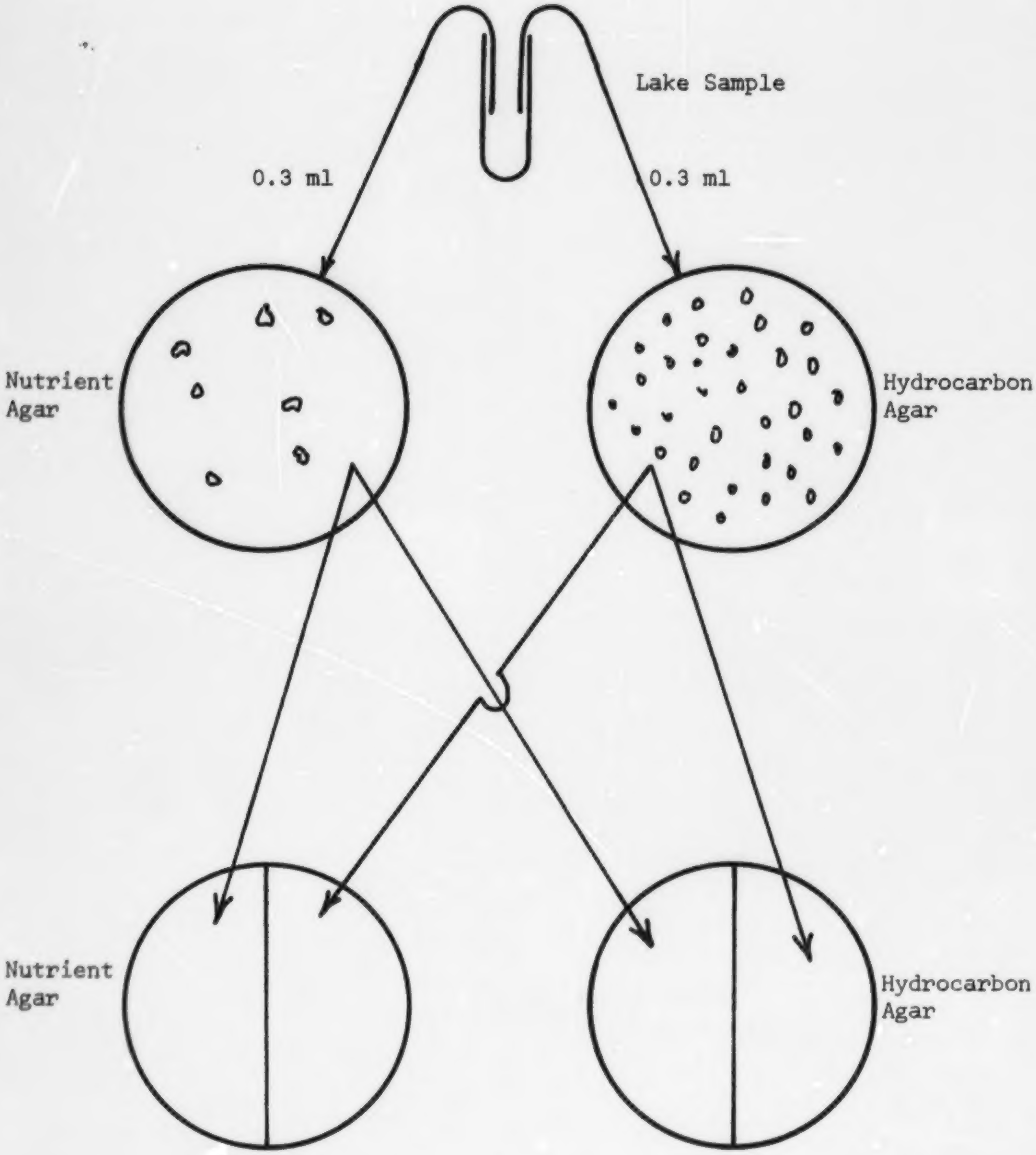
Lake Sample
0.3 ml
0.3 ml
Nutrient Agar
Hydrocarbon Agar
Nutrient Agar
Hydrocarbon Agar

Figure 10 - Metabolite Toxicity Test

If this was true, an explanation for the great difference in numbers of colonies may have been that on nutrient agar, easily metabolizable nutrient was available throughout (agar was quite homogeneous), hence colonies were allowed to grow to great proportions, perhaps overlapping each other so that distinct colonies were not easily detected. On the other hand, the petroleum agar was essentially an emulsion, i.e. oil droplets suspended throughout an agar-water phase. This meant food (oil) was not so easily obtainable (droplets may have been far apart) and the size of such droplets limited the amount of metabolizable material available to the cell, therefore, limiting colony growth.

Pure Culture Studies

These experiments with isolate YS-25 were done to ascertain petroleum hydrocarbon metabolism using batch culture techniques. The organism was isolated from Dunham Bay and belongs to the genus *Pseudomonas*.

In these studies, 25 mg of motor oil was emulsified in 250 ml distilled water using a Waring blender, with 3 minute blending time. This emulsion was then inoculated with YS-25 prepared as follows: a loopful of slant culture was thoroughly mixed into 5 ml sterile distilled water. A 1 ml aliquot was withdrawn and introduced into each 250 ml oil-water emulsion. The inoculated medium in a one-liter Erlenmeyer flask was incubated in a gyratory water bath to maintain a constant temperature (25°C) and a constant rapid aeration rate.

At various time intervals throughout the incubation, aliquots were withdrawn. A sample was removed from this aliquot, diluted serially in water, then plated on nutrient agar and petroleum agar.

The nutrient agar and petroleum agar plate counts for these culture studies have been analyzed.

Table 12 indicates the cell concentration in the identical culture flasks at various time intervals in the incubation. These data show trends in population growth. Populations at initiation of incubation were large. In several cases, population size seemed to increase, but in every case decreased to nearly negligible numbers by 24 hours of incubation. This could mean that the utilizable components of the motor oil were limiting. When exhausted, the population size fell. Another possibility is that some toxic substance was produced by an early metabolic process, thereby preventing further growth. Perhaps the oil concentration of the emulsion, though small, was still so great that cells absorbed oil to their surfaces and were either unable to metabolize the oil or were unable to survive because diffusion of other necessary substances became impossible.

Sediment Storage Study

Before any sediment studies were made, it was necessary to assess the effects of storage of sediments. Sediments were collected. An aliquot was analyzed for oxygen uptake capacity in a Warburg respirometer. The remainder was stored at 4°C for subsequent analysis after various intervals of time. There was less than 7.5% variation in the quantity of sediment employed during the study.

The oxygen uptake curves, shown in Figs. 11-14, indicate that low temperature storage of sediments is possible for at least 48 hours. Long term storage (9-11 days) resulted in a marked suppression of O_2 uptake activity. Samples were always analyzed within the 48 hour period. These data also show that replication is sometimes a problem (Fig. 11).

Oxygen Uptake Studies

One way of estimating the decomposition capacity of lake sediments is the measurement of the oxygen consumed during incubation of the sediment for a given period of time. Oxygen uptake rates were measured in Warburg respirometers. This measurement reflects the oxidative metabolism of hydrocarbons and hydrocarbon residues as well as any other oxidizable substrates associated with the sediment. In general, measurements of the endogenous oxygen uptake were greater than or similar to the measurements of the oxygen uptake in the presence of additional substrate. This implies that the microflora was substrate saturated and was working at maximum velocity with respect to the chemically complicated substrates available to it. It also may imply some physical or chemical interference by the oil at the level employed.

The addition of more microflora would increase the net uptake, but this would also increase substrate level proportionately if added as sediment. The uptake rates obtained in Warburg analysis of the lake sediments are presented in graphical form in Figs. 15-19. In addition, there is a table summarizing the Warburg data on the basis of specific uptake rates (microliters oxygen uptake/gram dry sediment/hr at maximum velocity).

Table 13 illustrates an interesting trend in Dunham Bay Station 4. The maximum activity was seen in the early spring. This activity reached a low early in July and rose again over the July 4th weekend.

Radioisotope Uptake

A technique that has been developed in our laboratory for estimating the metabolic activity of aquatic heterotrophic microflora has been used on selected water and sediment samples in this study (13).

In this assay, the rate of incorporation of C^{14}-glucose is used to monitor the growth rate of the microflora. The assumption is made in this assay that glucose is utilized by all heterotrophic microflora. Prior concentration of the water samples is needed for sufficient sensitivity and minimum use of isotopes. This is done by an overlay method that has been described by Clesceri (14).

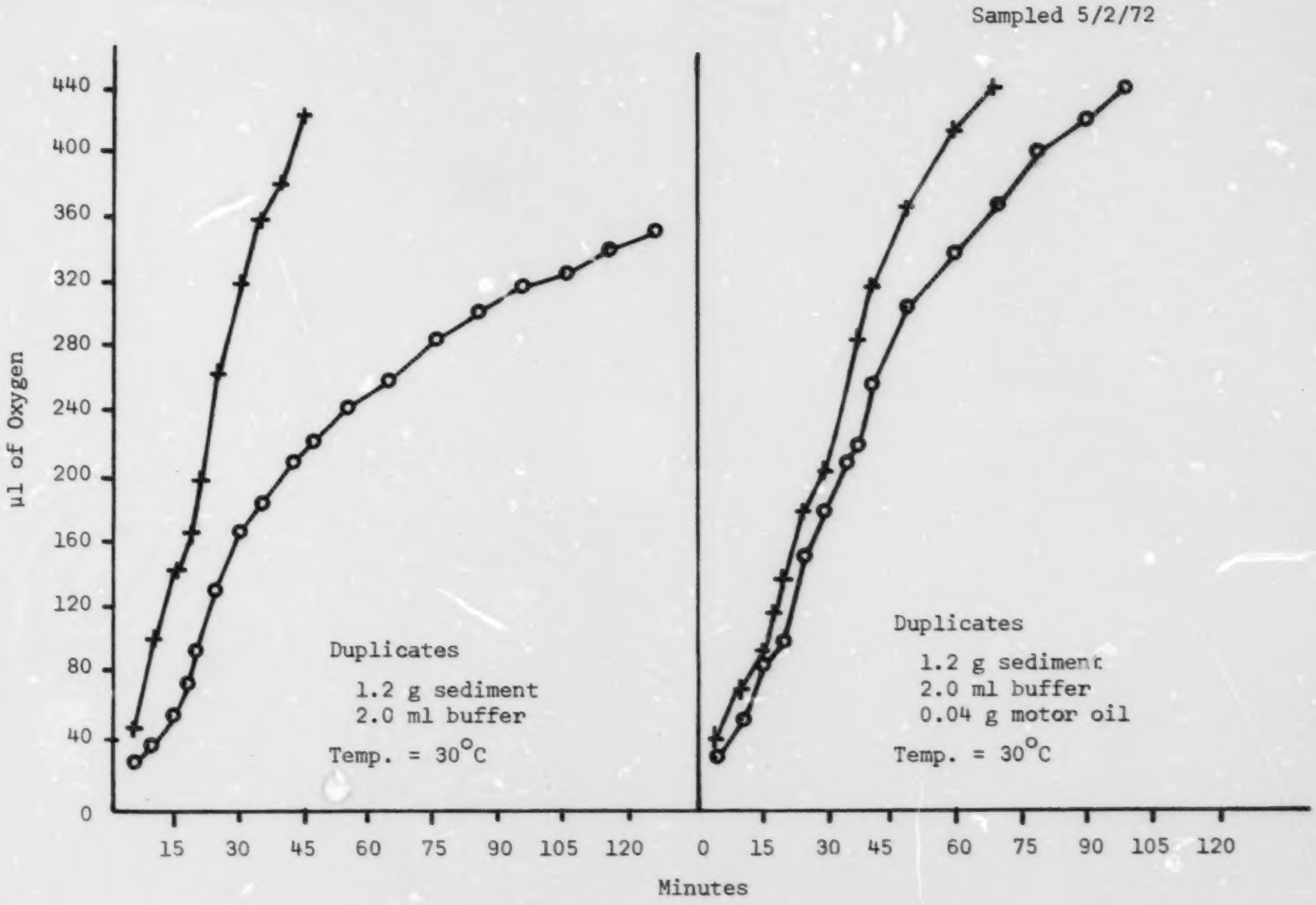

Figure 11 - Sediment Storage Study
(24 hours)

Sampled 5/2/72

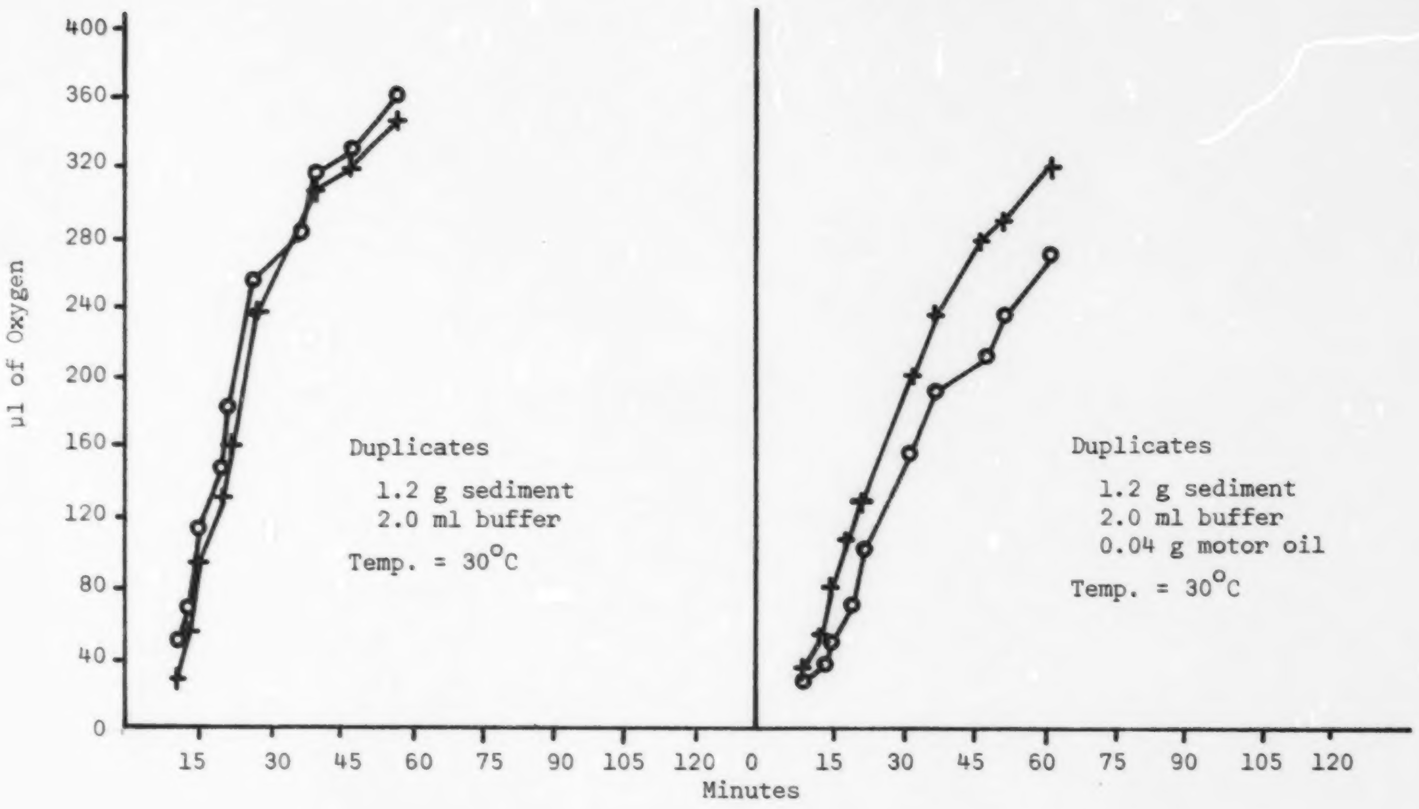

Figure 12 - Sediment Storage Study
(48 hours)

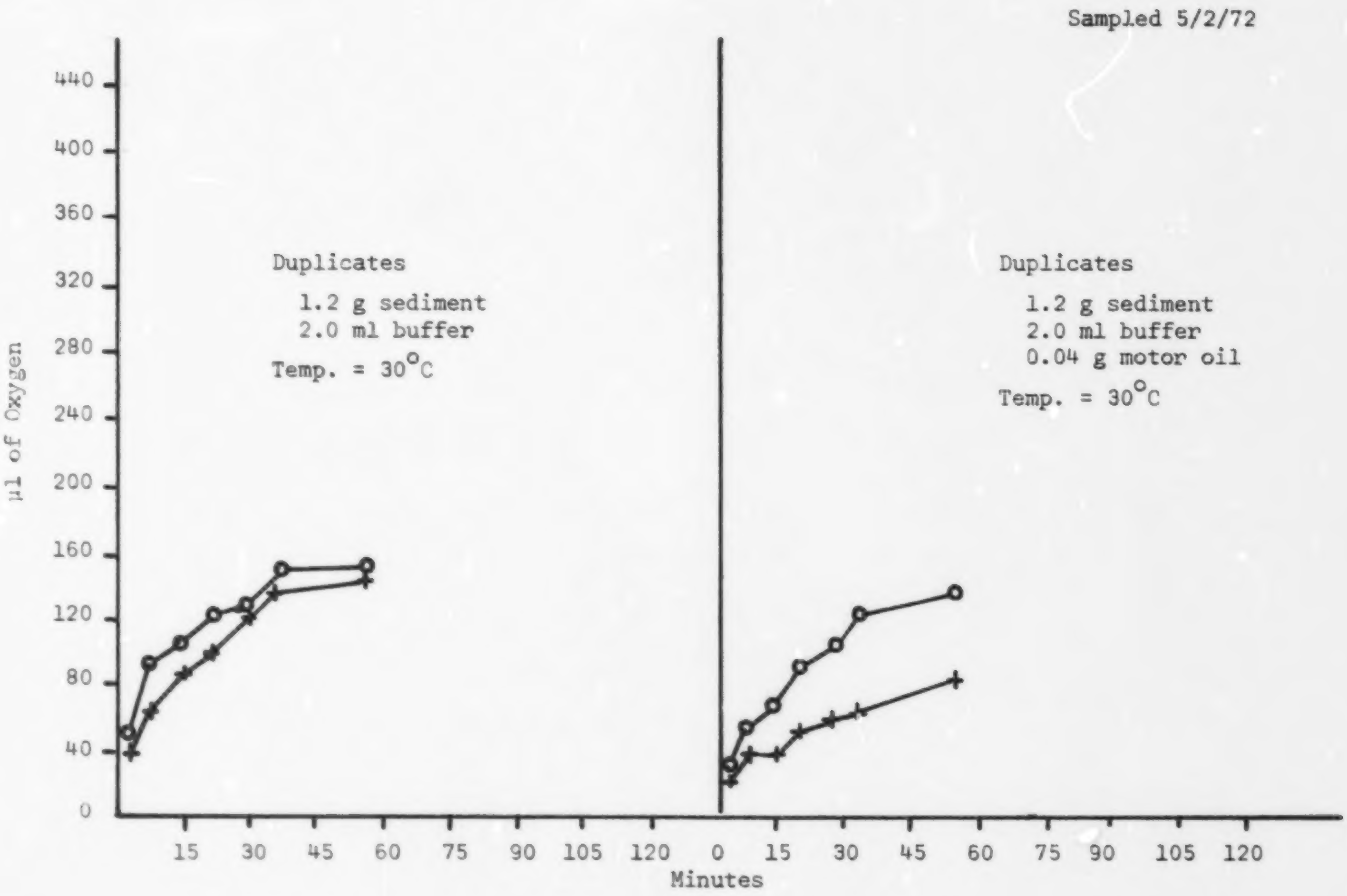

Figure 13 - Sediment Storage Study
(216 hours)

Sampled 5/2/72

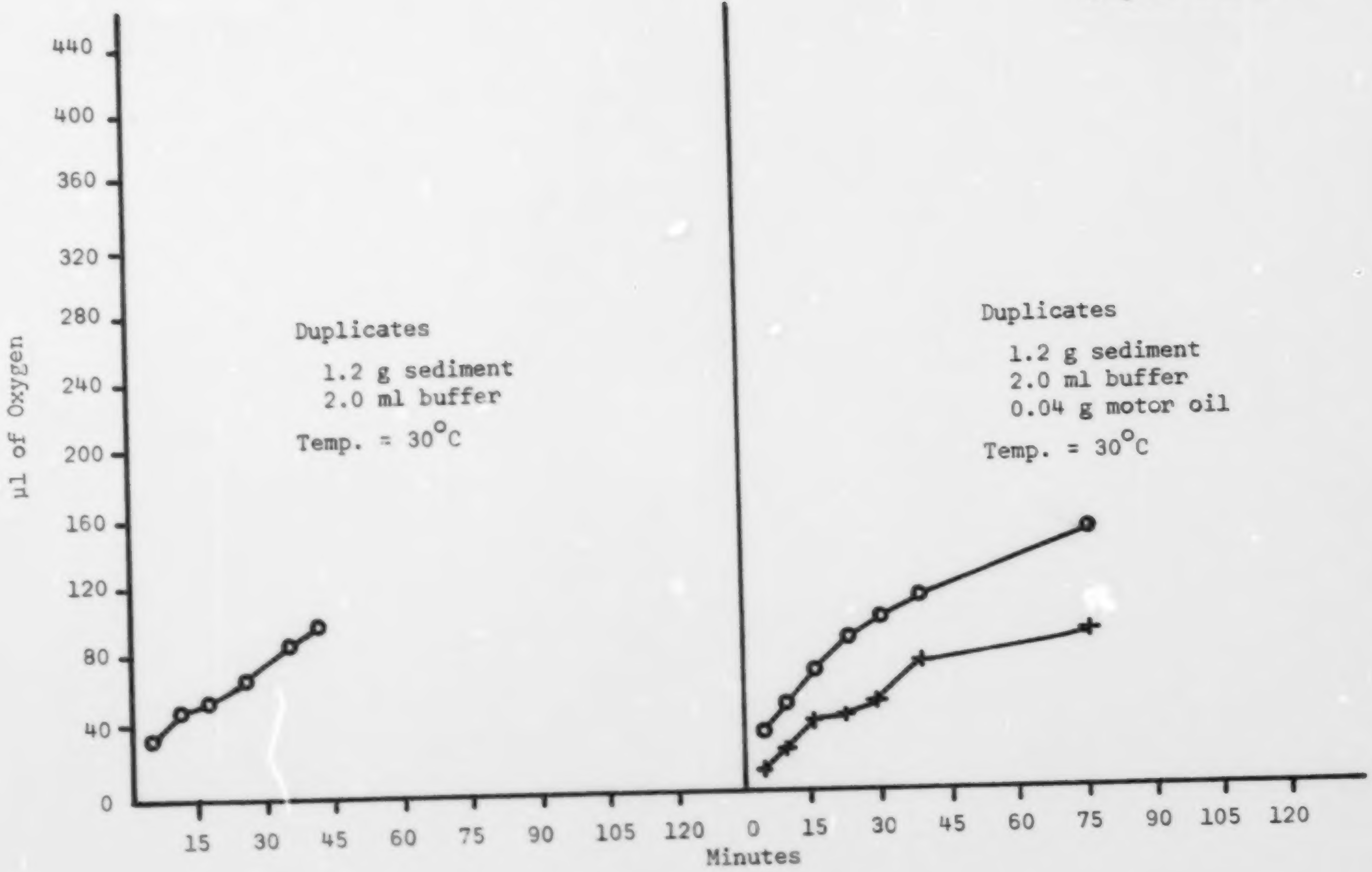

Figure 14 - Sediment Storage Study
(336 hours)

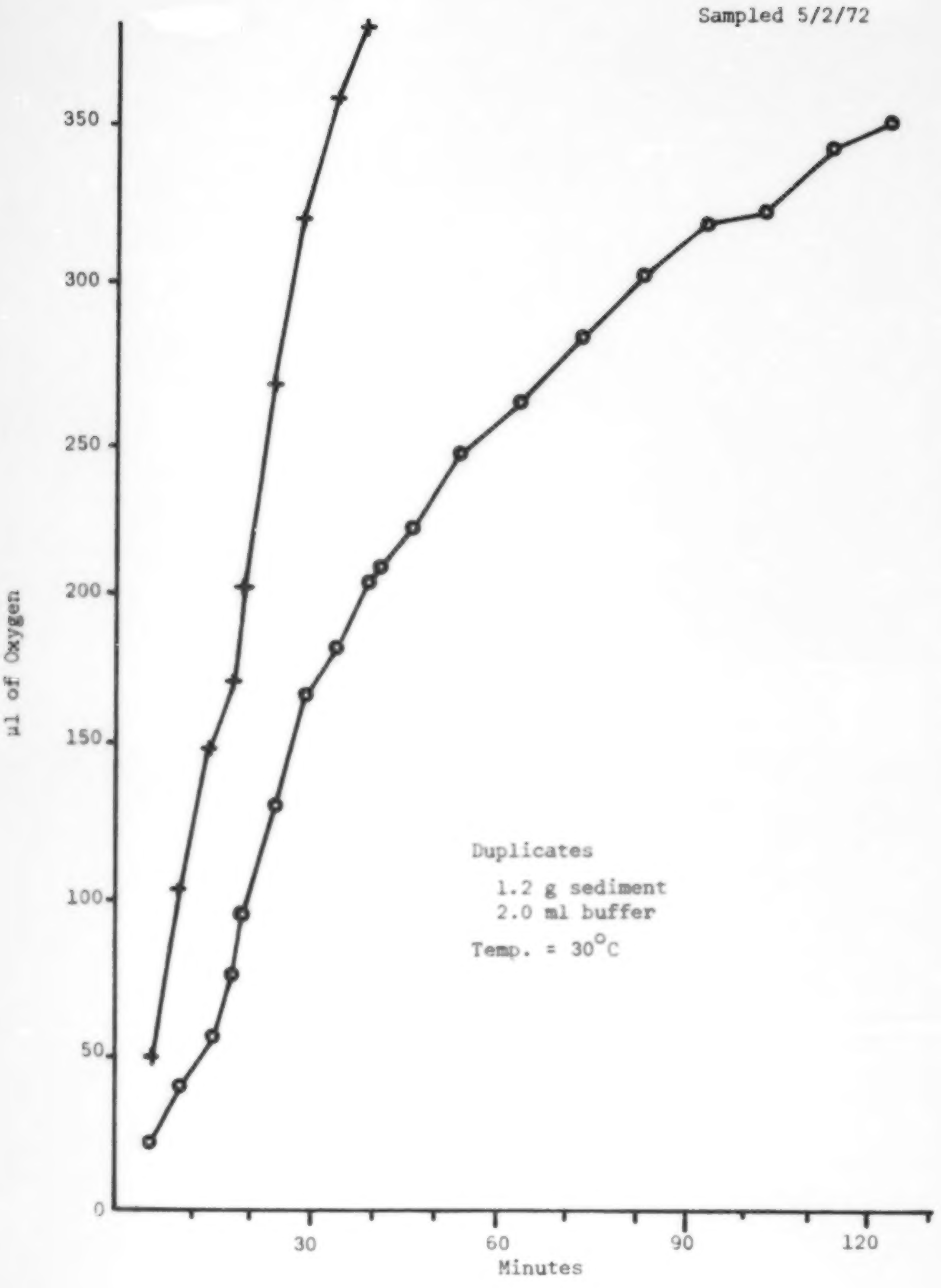

Figure 15 - Endogenous Respiration
Dunham Bay Station 4

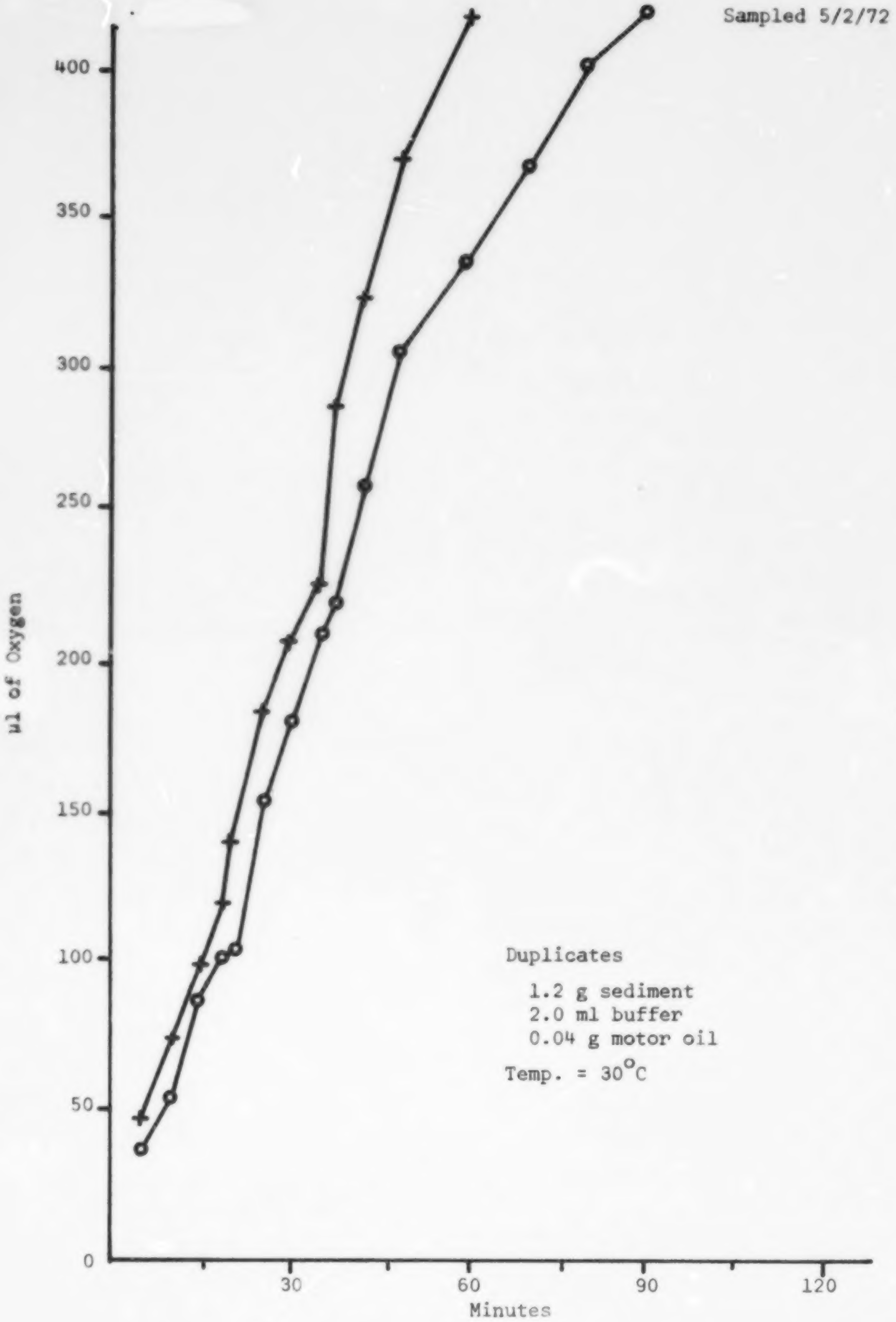

Figure 16 - Substrate Respiration
Dunham Bay Station 4

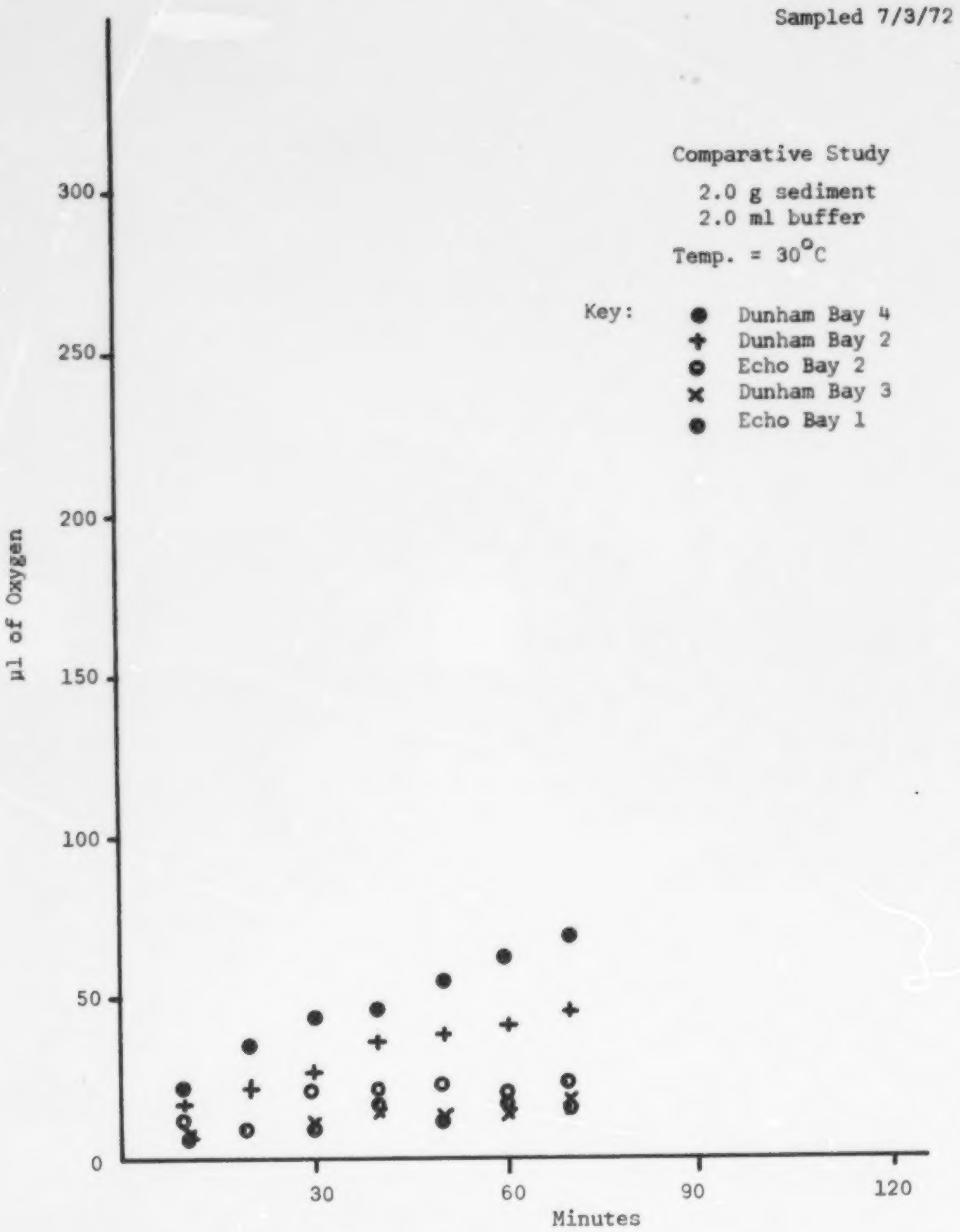

Figure 17 - Endogenous Respiration

Sampled 7/4/72

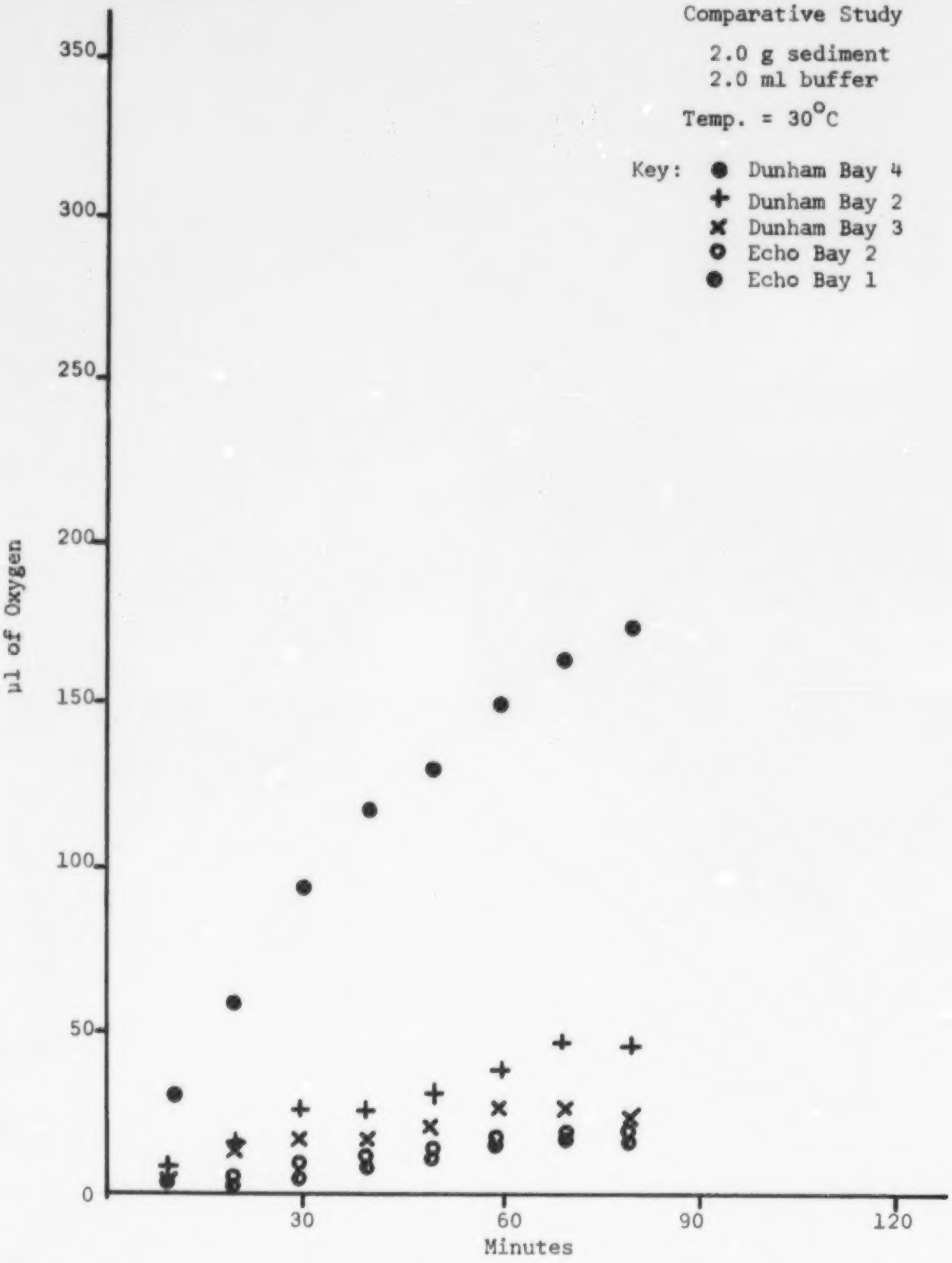

Figure 18 - Endogenous Respiration

Sampled 7/6/72

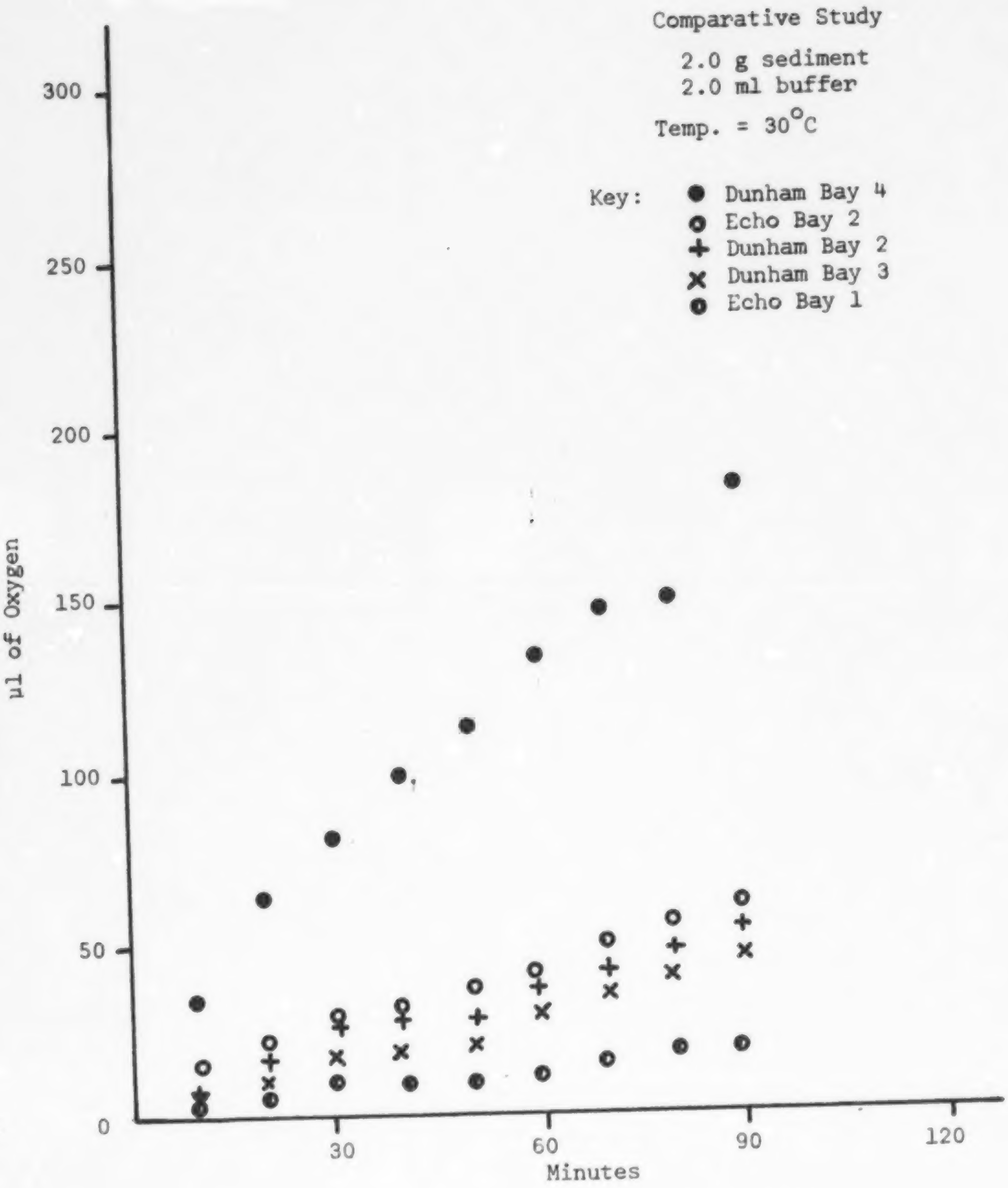

Figure 19 - Endogenous Respiration

Table 13

Microliters Oxygen Uptake/Hour/1.0 GM Dry Sediment

	Dunham Bay			Echo Bay		
Dates	Station 2	Station 3	Station 4	Station 1	Station 2	
5/2/72			4440* 3280*+			endog. 0.04g oil
6/1/72			1430			endog.
7/3/72	59	30	73	21	53	
7/4/72	102	132	555	42	26	endog.
7/6/72	77	158	710	41	89	endog.

*average of duplicate runs

+respiration in presence of 0.04 g of oil; all others are endogenous

Incorporation rate of the water samples is looked at as a function of number of cells as determined by plate count. This gives a specific activity of the microflora which can be related to chemical, physical, or other biological aspects of the system.

Some isotope studies were done for surface water in Dunham Bay and for the water column in both Echo Bay and Dunham Bay.

Isotope studies were done on sediments from all three bays. These studies are shown in Figs. 20-22.

Discussion

The field survey for cell concentrations in surface waters and the water column indicated that no significant differences occurred with respect to sampling station or date of sampling. A possible exception is that occasional highs were found at Station 4 in Dunham Bay. There was a one hundred-fold increase in cell count at this station over the July 4th weekend, but scattered equivalent highs at Dunham Bay Station 4 on 8/7 and Echo Bay Station 1 on 8/21.

Studies of biodegradability of oil and oil products by natural microflora in the water column and surface waters were limited by the low concentrations of heterotrophic microflora found in Lake George. Therefore, an isolate (YS-25) that grew well on petroleum agar was used as a test organism for pure culture studies of biodegradability. Although the organism proliferated on petroleum agar, growth in an oil-water mixture was not apparent. The concentration of oil in the oil-water mixture was 1/5 of that used in the petroleum agar. This was necessary to avoid a surface film in the oil-water mixture which may have interfered with oxygen transfer. Growth on petroleum agar occurred without the addition of yeast extract to the agar, although it was routinely added to enhance the size and number of colonies in field studies. The failure to produce growth in the oil-water mixture may be due to the absence of trace nutrients supplied by the agar itself.

Radioisotope studies permitted the examination of the activity of the microflora in water and sediment. Although these studies of "heterotrophic potential" only indirectly implicate the effects of oil in the ecosystem, there is some evidence that the July 4th weekend activities stimulated the sediment microflora in Dunham Bay, but not in Echo Bay. For equal quantities of sediment, the heterotrophic potential for Dunham Bay rose during the period 7/4 to 7/6, whereas the heterotrophic potential for Echo Bay fell. This could be attributed to addition of metabolizable carbon compounds from outboard engine waste to a carbon limited system or to increased mixing.

The oxygen uptake activity of the sediments possibly reflects differences in the composition of the organic material available for oxidation in the sediments. On the other hand, these data may reflect changes in the microbiological population such that organisms of shorter generation times

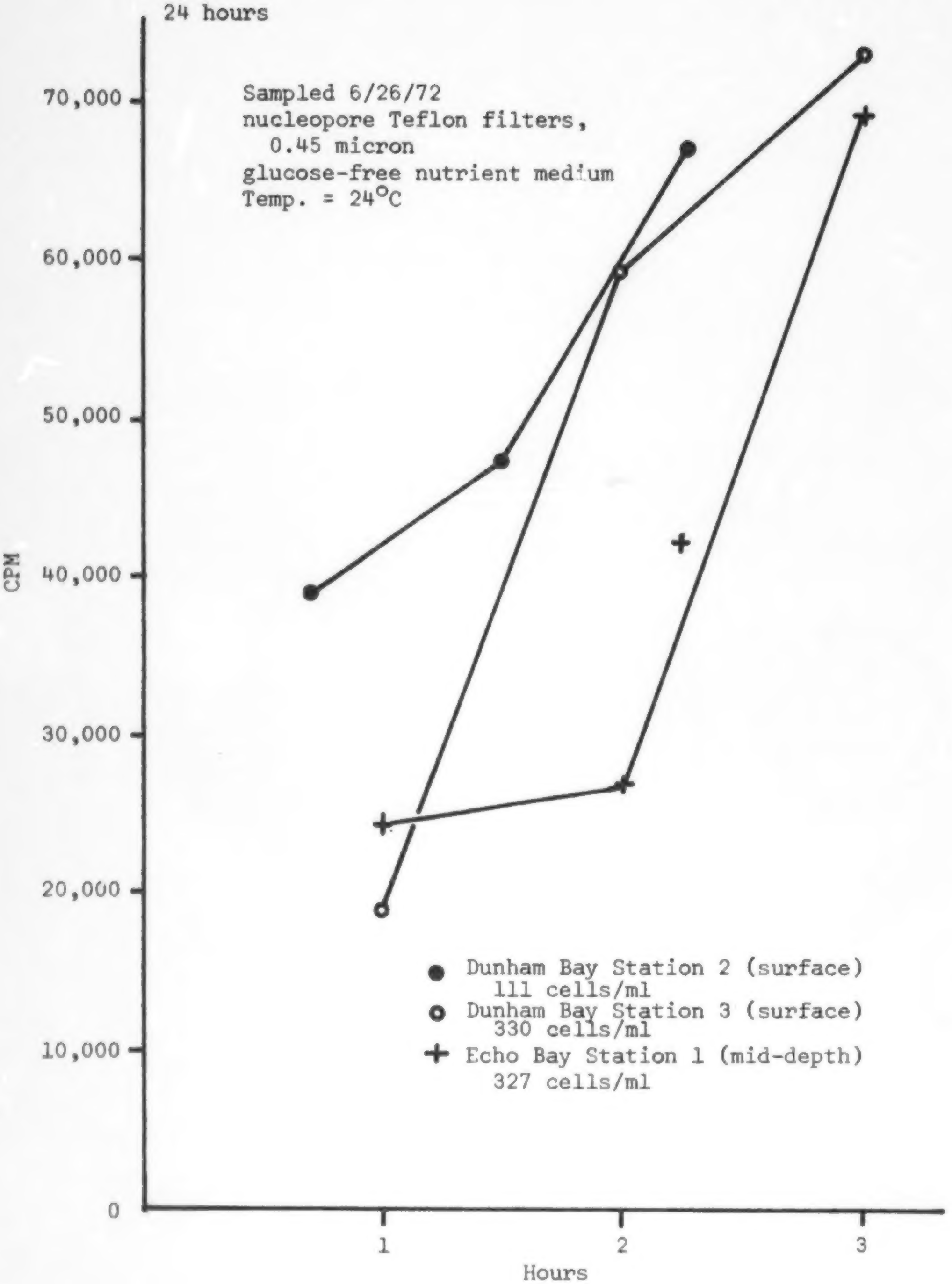

Figure 20 - Heterotrophic Potential: Water

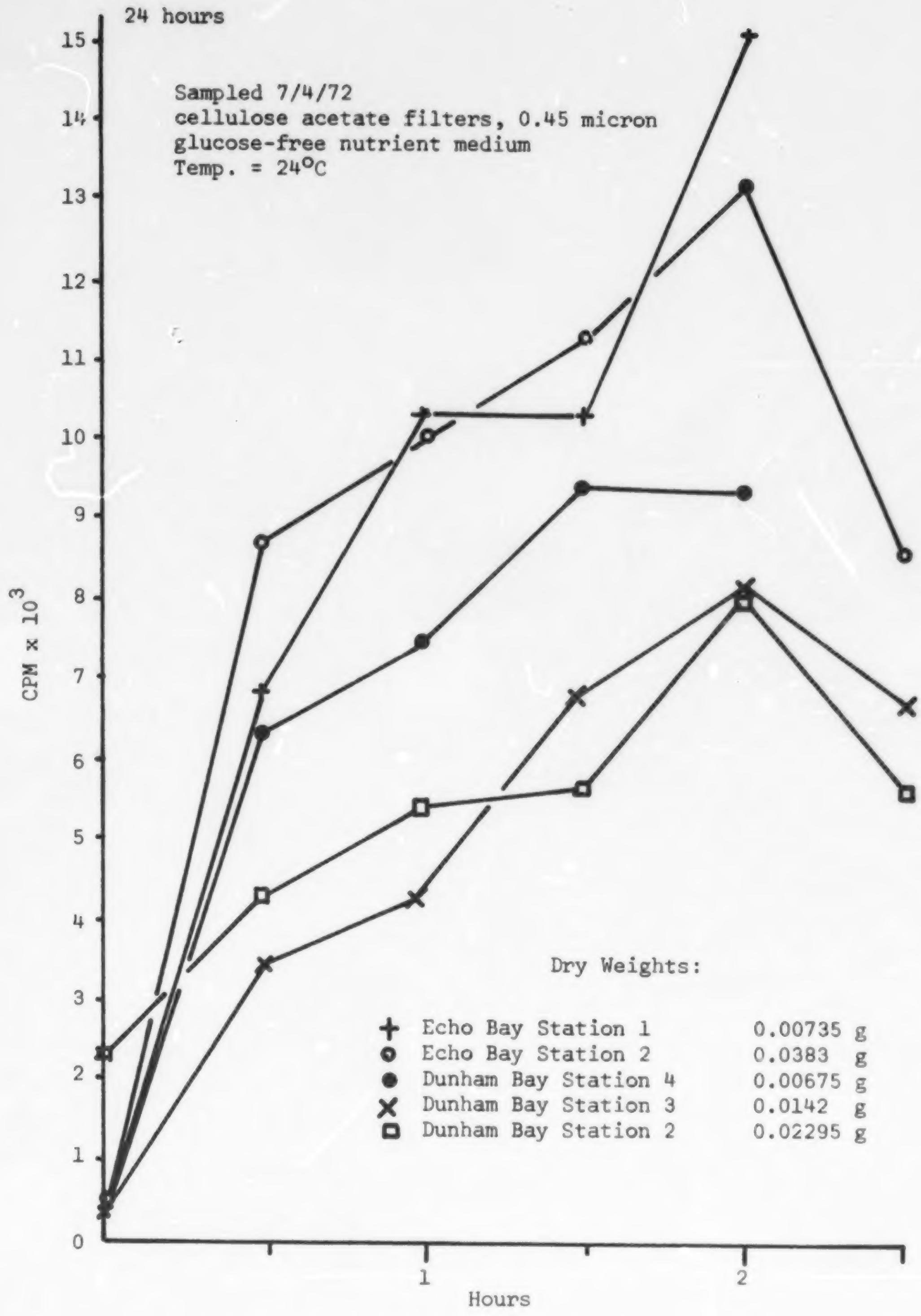

Figure 21 - Heterotrophic Potential: Sediment

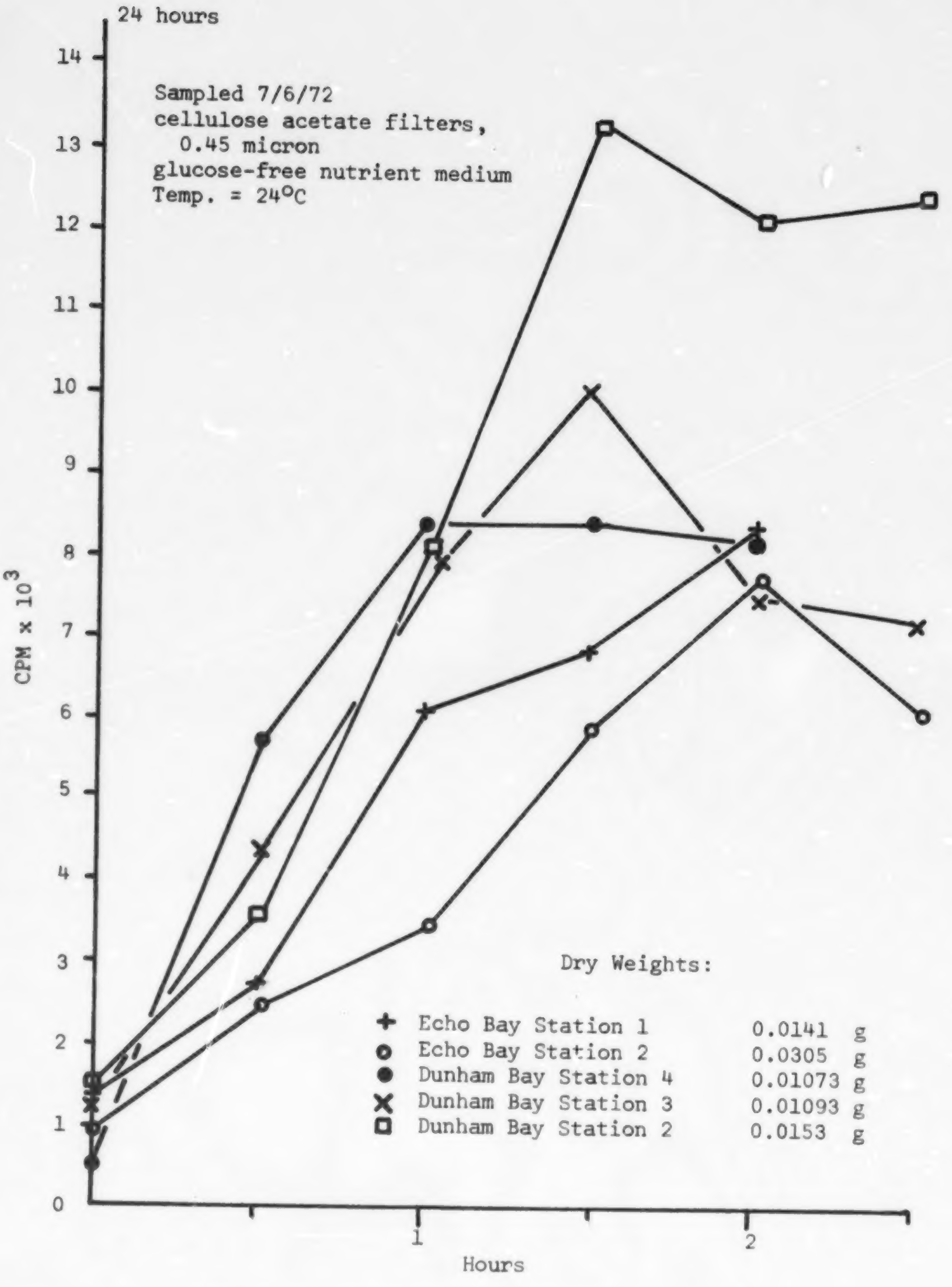

Figure 22 - Heterotrophic Potential: Sediment

predominate during periods of high oxygen uptake, and the converse in periods of low oxygen uptake. However, since a rather drastic change occurs in the short interval 7/3 to 7/6, it seems that the variation in oxygen uptake is more likely a function of chemical composition.

If the lack of stimulation of initial oxygen uptake by oil on 5/2 was due to substrate saturation as indicated earlier, perhaps there is significance in the divergence that occurred in one of the endogenous samples after prolonged incubation. (Fig. 15)

Since decomposing heterotrophs are opportunists in the sense that they respond quickly to the introduction of suitable substrate to their environs, it is reasonable to assume that the microflora (heterotrophic) is relatively constant with respect to size of population and that variation in activity is a function of temporary population expansion. As the newly introduced substrate becomes depleted, the population is returned to the normal level as these microflora are consumed by zooplankton, autolyze, or otherwise transported out of the system.

The introduction of wastes from outboard engines may play a role in these activity pulsations but positive proof would require chemical identification of the organics utilized by the microorganisms.

SECTION VI - EFFECT OF OUTBOARD ENGINE EXHAUSTS ON PHYTOPLANKTON

INTRODUCTION

Little research has been conducted on the effects of oil discharges on fresh water algae. The low level pollution of lakes and rivers from the recreational use of outboard engines has gone almost unnoticed until recently. Some work has been done (3,22,49) but primarily to establish the polluting nature of the outboard engines. The purpose of this segment of the research has been to examine and evaluate any effects which outboard engine exhausts may have on the phytoplankton of Lake George, New York, especially the effect on phytoplankton ability to fix CO_2 in the presence of crankcase drainage.

Plankton tow samples were collected for identification of major algal species present in each bay. In addition, water samples were collected with a VanDorn bottle to determine the immediate effect of outboard engine discharges on indigenous phytoplankton in their natural population density using radioisotope dilution techniques.

Phytoplankton are an important part of the aquatic food chain. Any adverse effect on primary productivity, due to unnatural or exogenic causes such as outboard engine discharge, may influence the entire aquatic community. In order to determine acceptable limits of discharge, a definition of the degree and influence which the operation of two cycle outboard engines has on phytoplankton is essential. Therefore, this research, which was aimed at measuring the response of algae to discharges from outboard engines, should aid communities and agencies in water resources planning and management.

Most oil pollution research has been conducted on marine environments. Mitchell et al. (47) enumerated the effects which oil could have on the total ecosystem, especially the many ways it could affect living organisms. Toxicity of oil, however, varies according to the composition of the petroleum product. Saunders et al. (66) noted that crude oils were not very toxic. The toxic properties are greatly increased by refining processes. According to Swift et al. (84) many petroleum products are highly toxic to fish and shellfish even in small concentrations. If present in sufficient concentrations, they may kill aquatic plants. However, the effect is mostly of short duration unless exposure to oil is continuous or periodic. Nutrient release from plant and petroleum decomposition may result in more luxurious growth of rooted plants. Their studies also indicated that the growth of marine algae often is enhanced, since populations of invertebrates which normally graze on them are reduced by the toxic substances.

Spooner (72), describing the biological effects of the Torrey Canyon disaster, observed that "on the whole, there seems to be a general survival of algae, as the serious damage is sporadic". In her studies, the damaged algae showed some signs of recovery after four to five weeks. Tenderon (86) also discussed the effects of the Torrey Canyon disaster and pointed out that marine birds suffered the most from oil pollution and that there did not seem to be a high mortality rate in the flora.

LaRoche et al. (42) have described bioassay procedures for oil and oil dispersant toxicity evaluation in the marine environment. In general, they found crude oils (West Texas, Kuwait, Lagumillas) to be far less toxic to shrimp and other marine species in 96 hours than were refined oils.

Tarzwell (85) summed up the effect of oil on aquatic organisms in the following words: "The effects of oil on aquatic organisms are very diverse and complex. Oil on the surface may limit oxygen exchange, entangle and kill surface organisms, contaminate organisms which come to the surface only occasionally, contribute water soluble materials which are toxic, contain volatiles which may produce toxic conditions before their release and result in the production of degradation products, which are toxic or are contaminants, coat the gills of aquatic organisms or produce solid tar-like masses." He further states that oil spillages or leakages from oil wells, barges and tankers along our coast, have resulted in harmful effects to the marine biota. Water soluble portions, volatile fractions, and breakdown products such as naphthenic acids have injured or killed certain aquatic life. Direct contact with the oil interferes with gaseous exchange at the air-water interface and respiration.

Hardy (30) points out that a layer of hydrocarbon on a water surface interferes with gaseous exchange between the atmosphere and sea water. The opacity of the hydrocarbon film has an adverse effect on the photosynthesis of algae. Clendenning (12), in a controlled laboratory experiment, observed that a film 0.02 mm thick on sea water did not affect the photosynthetic activity of Macrocystis pyrifera during 24 hours exposure at 22°C, but the photosynthetic activity stopped completely after three days.

In a review paper on occurrence, effects and fate of oil polluting the sea, Zobell (95) noted that oils have a relatively high oxygen demand and may result in oxygen depletion in certain oil polluted waters. From the observations made by various workers on the toxicity of oils on phytoplankton, he concluded that phytoplankton seemed to be injured only by continuous prolonged exposure to large amounts of oil. Such conditions, he noted, prevailed only in exceptionally heavily polluted areas such as tidepools, seaports and settling ponds or lagoons.

Galtsoff et al. (26) reported normal growth of diatoms in an aqueous medium overlayered with various kinds of mineral oil. They also found that water soluble extract from 12% crude oil stimulated growth of most diatoms while extract from 25% crude oil retarded the growth and extract from 50% crude oil stopped the growth of all diatoms. Clendenning (12) found that a 1% emulsion in sea water reduced the photosynthesis of *Macrocystis* to 73% of that in the control sea water after 24 hours stopping it completely in three days. An emulsion of 0.1% produced essentially the same effects.

Biological effects of oil pollution in fresh water have been discussed by McCauley (45). Oil pollution of the Muddy River (Massachusetts) was caused by an oil spill of heavy bunker oil. In a two year study on this polluted river, McCauley reported definite correlations between the plankton populations and the degree of oil pollution. The toxic effect of oil was found to be pronounced on the macrofauna of the sediments and on the planktonic organisms. Species of the following plankters were found to tolerate the highest concentrations: *Lyngbya*, *Oscillatoria*, *Ankistrodesmus*, *Chlamydomonas*, *Closterium*, *Gonium*, *Scenedesmus*, *Asterionella*, *Cyclotella*, *Fragilaria*, *Meridion*, *Navicula*, *Tabellaria*, *Euglena*, *Trachelomonas*, *Voricella*, *Aspanchna*, *Keratella*, *Polyarthra*, *Cyclops*, and *Nemata*. The highest concentration of oil in water, reported as a mean value at the station, was 221.3 ppm.

Experiments conducted by English *et al*. (21,22) with outboard engine exhausts indicated a definite tainting of fish flesh even with large quantities of water per gallon of fuel consumed. They also found oily taste in the flesh of fish that had been exposed for a week to an outboard engine exhaust water equivalent of 37,700 gallons of water per gallon of fuel consumed. They concluded that unusually low water volumes per unit of fuel consumed were necessary for severe pollution to result exclusively from emissions of outboard engines.

The literature reviewed above shows lack of unanimity on the part of researchers as to the effects of oil pollution on phytoplankton. Very little research has been done, so far, on the effects of outboard engine exhausts on algae and a necessity for further research in this field is indicated.

MATERIALS AND APPARATUS

Chemicals

1. Sulfuric acid and hydrochloric acid, reagent grade
2. Sodium bicarbonate - $NaHC^{14}O_3$ from New England Nuclear, Boston, Massachusetts - sp. activity 10 μg/μc
3. Omnifluor - a blend of PPO (98%) and BIS-MSB (2%) from New England Nuclear, Boston, Massachusetts
4. 1-4, Dioxane Scintanalyzed from Fisher Scientific Company
5. Naphthalene, for liquid scintillation cocktails, from Beckman Instruments, Inc.
6. Chemicals for synthetic algal nutrient medium as listed on pages 11 and 12 of Algal Assay Procedure, Bottle Test, by EPA, August 1971 (23)

Materials

1. Plankton tow with a nylon net, No. 20, aparture 80 microns, inlet diameter 4 inches
2. Sample containers, plastic, one liter capacity
3. Microscope, Zeiss, RA type with inclined binocular body
4. Microscope slides, cover glass and immersion oil
5. Filtering apparatus and 0.45μ membrane filters (Millipore HAWP type)
6. VanDorn bottle, 4.1 liter capacity
7. Temperature and D.O. meter (Model 54 oxygen meter supplied by Yellow Springs Instrument Company, Yellow Springs, Ohio)
8. pH meter, stirrer, etc.
9. Milk dilution bottles, 160 ml capacity
10. Liquid scintillation counting vials, screw cap, foil lined, 22 mm neck, supplied by New England Nuclear, Boston, Massachusetts
11. Test algae, *Selenastrum capricornutum* Printz, *Microcystis aeruginosa* Kutz, and *Anabaena flos-aquae* Lyngb, Source: National Eutrophication Research Program, Pacific Northwest Water Laboratory, EPA, Corvallis, Oregon

Apparatus

1. Incubator Box

The incubator box, commonly known as a photosynthetic environmental control chamber, consisted of a water-tight plexiglas tank with inside dimensions of 7" x 11" x 15". The milk dilution bottles (54 can be accommodated) are held in 1 1/4" wide stainless steel clips which are mounted on 1 1/2" wide and 6" diameter plexiglas discs. The discs are rotated by means of a gear motor at 6 rpm to effect continuous mixing of the sample. The plexiglas tank is enclosed in a plywood box and is provided with two sets of four cool white fluorescent lights, one set on each long side and 4 inches from the outside of the tank. The light intensity can be varied by means of a dimming system provided in the box. Maximum light available to algae was about 1200 foot candles. Lake water was continuously circulated through the incubator box to maintain the water samples at approximately the lake temperature.

2. Liquid Scintillation Counter

A Liquid Scintillation System, LS-133 (Beckman Instruments, Inc., Fullerton, California) was used throughout this study.

LS-133 is an ambient temperature scintillation counter and is equipped with a Model 33 Teletypewriter for data print-out. It has a conveyor chain with 100 sample positions which are automatically sequenced by photoelectric cells. The instrument is primarily designed to count H^3, C^{14}, and P^{32} or a mixture of these radioisotopes.

PROCEDURE

Plankton tow samples were collected from the three bays. Vertical plankton tow samples were obtained from two stations in each bay. The volume of water that passed through the plankton net was calculated for each tow. The samples were collected in one-liter plastic containers and usually examined on the day of collection. When not being examined, the samples were stored at 3°-5°C in a cold room. Identification and enumeration of algae followed the method described by Edmondson (19). The only variation in this procedure was that algae under the whole cover glass were counted instead of counting algae in two transects. The effects of outboard engine exhausts were determined by the radioisotope dilution technique introduced by Steeman-Nielsen (74) to be used in oligotrophic waters and in waters with a photic zone of greath depth. The method has since been modified by Ryther (63), Goldman (27), and others. It consists of adding a known amount of $NaHC^{14}O_3$ possessing a high C^{14} activity to lake samples and incubating for a known period of time (3 hours). The sample is filtered through a membrane filter, 0.45µ pore size, and the activity of the retentate is determined which provides a measure of CO_2 fixed.

Water samples were taken with a VanDorn bottle, from one station in each bay at a depth of 2 meters. This depth was selected because it was always in the photic zone and the algae in this zone are not subjected to intensive light. Temperature and D.O. were measured at the time of sampling. The pH of the sample was measured and alkalinity was obtained by titrating it with 0.02 N H_2SO_4 to pH 5.0.

One hundred ml of lake water samples were placed in milk dilution bottles, 160 ml capacity. Various amounts of crankcase drainage (collected with a Kleen Zaust, Goggi Corporation, Staten Island, N. Y.) were added to make up 0 (control), 1, 5, 10, 20, 30, and 50 ppm (by volume) samples. Three replicate light bottles and two replicate dark bottles were prepared for each concentration. Three µc of C^{14} as $NaHC^{14}O_3$ (unless noted otherwise) were added to each bottle. The mouths of the bottles were sealed with aluminum foil and then capped securely. These were then incubated in the photosynthetic chamber for three hours. This time period was considered reasonable since sufficient C^{14} would be fixed by those algae present to give reliable counts in a short counting time of one minute; it was not excessive to completely exhaust the available carbon or other essential elements which might limit the growth of these organisms.

The samples were then filtered through 0.45μ membrane filters under a low vacuum. The algae retained on the filter were washed with 20 ml of lake water to remove any radioactive carbon adsorbed onto the algae or soaked in the membrane filter. The membrane filter and the C^{14} labelled cells retained on it, were dissolved in 10 ml of scintillation cocktail in a liquid scintillation counting vial. One liter of the scintillation cocktail was composed of 120 grams of naphthalene and 8 grams of Omnifluor dissolved in 1-4, dioxane. The activity present in each vial was measured, as counts per minute, in a liquid scintillation counter.

The rate of carbon assimilated can be obtained from the relationship:

$$\frac{C^{12} \text{ available}}{C^{12} \text{ assimilated}} = k \times \frac{C^{14} \text{ available}}{C^{14} \text{ assimilated}}$$

where k is a factor which corrects for the slower uptake of C^{14} as compared to C^{12} (26). It is seen from the above relationship that C^{12} uptake for a given sample is proportional to the C^{14} uptake.

The effect of various concentrations of oil-gas mixtures added to the sample can, therefore, be obtained by comparing the number of counts per minute for each sample with those of the control.

Similar experiments were also conducted with raw fuel (1:50 oil-gas mixture). The gasoline as well as the oil used in this research was obtained from Mobil stations in one batch.

Also, effects of water soluble extract of crankcase drainage on test algae were determined. Nutrient medium consisting of macronutrients and micronutrients, as detailed in Sec. 6 of the "Algal Assay Procedures, Bottle Test" by EPA (23), was prepared. About 6 ml of crankcase drainage obtained from a 33 1/3 HP Evinrude engine running at 1000 rpm, was added to approximately 6 liters of the nutrient medium and shaken thoroughly. This was then allowed to rest for a few hours. The medium was withdrawn from an opening at the bottom, leaving the oil film behind. The carbon content of the standard medium and that of the medium plus crankcase drainage was measured on a Beckman Carbon Analyzer. The difference in the two carbon measurements is due to the oil-gas mixture dissolved in the medium. More crankcase drainage had to be added to make up the highest concentration noted on Figs. 23-28. With 60 ml of this medium in each of the 250 ml flasks, algal assays were performed using test algae Selenastrum capricornutum (Printz), Microcystis aeruginosa (Kutz) and Anabaena flos-aquae (Lyngb). The method followed for the algal assay procedure is outlined in the above noted EPA brochure (23).

RESULTS AND DISCUSSION

Plankton tow samples (vertical tows) were collected during June through September in order to determine the predominant species of algae present in the three bays under study. Smith Bay has not been sampled as frequently as the other bays because of dock building activity occurring during most of the summer, 1972. In addition, a few drag samples (horizontal plankton tows) from one station to the other at Dunham and Echo Bay were also obtained during May and June, 1972.

Tables 14-25 have been prepared to include the number of different algae per liter of lake water for the algal genera observed from various samples. It is seen from these tables that Fragilaria, Asterionella, Dinobryon and Tabellaria were the predominant algal genera present in the bays during the period under study. Rhizosolenia is another genus which was present in sufficient numbers in the plankton tow samples of May and June. It is noticed that in both Dunham and Echo Bays Rhizosolenia began to appear in the middle of May, was in bloom by mid-June and disappeared almost completely by the end of June 1972. Echo Bay samples had twice as much Rhizosolenia as that found in Dunham Bay Samples. The highest concentration of Rhizosolenia in Echo Bay was approximately 7000 cells/liter. Dinobryon increased steadily since the middle of May and reached its maximum growth at the end of June. It disappeared almost completely at the end of August yet was observed again in the September samples.

Population concentrations of Asterionella and Fragilaria have varied during the period under investigation. In Dunham Bay Asterionella reached a peak concentration (27,600 cells/liter) on 6/26/72. However, in the 6/30/72 sample it had dropped to 1200 cells/liter. It began increasing in July samples and has been varying during the following months (August and September). Fragilaria demonstrated its peak population in the first week of July in Echo Bay and in the second week of August in Dunham Bay. In the plankton tow sample of 7/6/72 at Station 2, Echo Bay, the Fragilaria population density was estimated at 56,000 cells/liter. Dunham Bay, Station 2 had a maximum concentration of 40,000 Fragilaria cells/liter on 8/15/72.

Concentrations of Synedra populations have remained relatively stable during the period under investigation. Tabellaria has also remained steady except for a peak in the middle of August, when it reached the maximum concentration noted (6000 cells/liter at Station 2, Dunham Bay). Staurastrum and Spondylosium do show up at times but their numbers have been relatively low. The case is similar with Zygnema and Mougeotia which have made their appearance in only a few samples. Ceratium appeared at the end of June and reached a maximum population of 1500 cells/liter by the end of July, 1972.

It was observed that Fragilaria was the most abundant alga present in the three bays. On the average Echo Bay contained the largest number of organisms per liter and Smith Bay the least.

June samples had the highest concentrations of algal populations which decreased considerably by the last week of July, but recovered somewhat

Table 14

Predominant Algal Genera Found in Dunham Bay and Echo Bay

Sample 5/18/72

	Number of Organisms per liter	
	Dunham Bay Stations 2-3	Echo Bay Stations 1-2
Asterionella	140	1,050
Fragilaria	1,200	1,050
Tabellaria	720	360
Rhizosolenia	40	200
Navicula	40	-
Synedra	60	100
Staurastrum	-	10
Spondylosium	-	10
Dinobryon	100	70
Total	2,300	2,850

Table 15

Predominant Algal Genera Found in Dunham Bay and Echo Bay

Sample 6/12/72

	Number of Organisms per liter	
	Dunham Bay	Echo Bay
	Stations 2-3	Stations 1-2
Asterionella	560	2,950
Fragilaria	1,350	3,400
Tabellaria	0	2,880
Rhizosolenia	1,310	2,540
Navicula	20	10
Synedra	50	40
Pinnularia	0	0
Cymbella	10	0
Spondylosium	0	80
Dinobryon	210	430
Total	3,510	12,330

Table 16

Predominant Algal Genera Found in Dunham Bay and Echo Bay

Sample 6/19/72

	Number of Organisms per liter	
	Dunham Bay Stations 2-3	Echo Bay Stations 1-2
Asterionella	3,500	7,700
Fragilaria	8,000	7,600
Tabellaria	1,440	2,520
Rhizosolenia	3,500	6,700
Navicula	0	50
Synedra	50	110
Cymbella	0	30
Staurastrum	0	10
Spondylosium	120	600
Arthrodesmus	0	20
Mougeotia	0	100
Dinobryon	1,500	1,400
Total	18,110	26,840

Table 17

Predominant Algal Genera Found in Dunham Bay and Echo Bay

Sample 6/26/72

	Number of Organisms per liter			
	Dunham Bay		Echo Bay	
	Station 2	Station 3	Station 1	Station 2
Asterionella	4,800	27,600	49,800	37,200
Fragilaria	10,000	32,000	81,000	76,500
Tabellaria	1,080	3,420	7,200	3,600
Rhizosolenia	0	300	1,000	300
Navicula	0	0	0	900
Synedra	250	0	0	100
Staurastrum	100	200	200	0
Spondylosium	550	0	1,000	0
Zygnema	1,000	0	0	0
Dinobryon	4,800	5,700	5,100	4,000
Gomphospheria	0	0	0	100
Total	22,580	69,220	145,300	122,700

Table 18

Predominant Algal Genera Found in Dunham Bay and Echo Bay

Sample 6/30/72

	Number of Organisms per liter			
	Dunham Bay		Echo Bay	
	Station 2	Station 3	Station 1	Station 2
Asterionella	3,000	1,200	300	4,800
Fragilaria	7,500	4,000	2,000	18,500
Tabellaria	5,400	120	300	720
Navicula	50	0	50	0
Synedra	900	100	200	80
Staurastrum	200	20	20	400
Zygnema	500	0	0	0
Dinobryon	10,900	3,300	3,400	11,900
Ceratium	0	10	0	200
Total	25,950	8,750	6,250	36,600

Table 19

Predominant Algal Genera Found in Dunham Bay, Echo Bay and Smith Bay

Sample 7/3/72

	Number of Organisms per liter					
	Dunham Bay		Echo Bay		Smith Bay	
	Station 2	Station 3	Station 1	Station 2	Station 1	Station 2
Asterionella	9,000	600	600	4,800	3,000	17,000
Fragilaria	9,000	6,000	2,500	25,500	900	3,310
Tabellaria	600	600	120	2,400	0	360
Rhizosolenia	0	100	10	0	0	0
Synedra	100	100	0	40	10	60
Pinnularia	0	0	2	0	0	0
Staurastrum	0	0	0	10	60	60
Arthrodesmus	0	0	0	5	10	10
Cosmarium	0	0	0	10	60	0
Synura	100	0	10	10	0	0
Dinobryon	5,500	2,900	2,700	3,100	600	1,250
Ceratium	100	100	20	800	60	375
Total	24,400	10,400	5,962	36,675	4,700	22,425

Table 20

Predominant Algal Genera Found in Dunham Bay and Echo Bay

Sample 7/6/72

	Number of Organisms per liter			
	Dunham Bay		Echo Bay	
	Station 2	Station 3	Station 1	Station 2
Asterionella	4,000	5,000	1,500	15,000
Fragilaria	12,000	15,000	6,000	56,000
Tabellaria	2,000	500	800	7,000
Navicula	100	0	20	800
Synedra	0	0	20	400
Pinnularia	0	0	0	400
Staurastrum	100	80	100	400
Pediastrum	0	60	0	0
Dinobryon	3,000	1,500	2,000	12,000
Gymnodinium	0	60	0	400
Ceratium	0	100	100	1,000
Total	21,200	22,300	10,540	93,400

Table 21

Predominant Algal Genera Found in Dunham Bay and Echo Bay

Sample 7/10/72

	Number of Organisms per liter			
	Dunham Bay		Echo Bay	
	Station 2	Station 3	Station 1	Station 2
Asterionella	4,000	1,300	700	3,000
Fragilaria	25,000	10,000	10,000	5,000
Tabellaria	1,500	2,100	1,500	500
Cyclotella	0	50	0	0
Frustula	20	0	0	0
Staurastrum	800	0	80	100
Arthrodesmus	0	0	0	300
Pediastrum	60	50	80	0
Synura	0	30	0	0
Dinobryon	100	600	1,500	0
Sphaerocystis	20	0	0	0
Gymnodinium	0	0	50	0
Ceratium	0	0	700	80
Total	31,500	14,130	14,610	8,980

Table 22

Predominant Algal Genera Found in Dunham Bay, Echo Bay and Smith Bay

Sample 7/24/72

Number of Organisms per liter

	Dunham Bay		Echo Bay		Smith Bay	
	Station 2	Station 3	Station 1	Station 2	Station 1	Station 2
Asterionella	300	1,500	0	0	0	150
Fragilaria	8,000	10,000	1,500	150	600	1,500
Tabellaria	300	2,000	0	300	0	50
Navicula	300	0	40	100	30	10
Synedra	500	0	40	100	60	10
Pinnularia	0	0	40	0	0	0
Cymbella	0	0	0	100	0	0
Staurastrum	300	300	40	200	100	10
Arthrodesmus	300	300	0	100	30	0
Cosmarium	0	30	0	0	0	0
Zygnema	1,000	0	0	0	0	0
Spirogyra	1,000	0	0	0	0	0
Dinobryon	500	0	0	0	0	0
Ceratium	0	0	40	1,500	100	30
Euglena	1,000	300	200	700	0	0
Total	13,500	14,430	1,900	3,250	920	1,760

Table 23

Predominant Algal Genera Found in
Dunham Bay, Echo Bay and Smith Bay

Sample 8/15/72

	Number of Organisms per liter					
	Dunham Bay		Echo Bay		Smith Bay	
	Station 2	Station 3	Station 1	Station 2	Station 1	Station 2
Asterionella	20,000	3,000	2,000	3,000	200	0
Fragilaria	40,000	5,000	8,000	6,000	20	6,000
Tabellaria	6,000	400	3,000	800	200	0
Navicula	0	0	0	0	0	1,000
Synedra	100	0	0	400	0	150
Cymbella	50	0	0	0	20	0
Cyclotella	200	0	0	40	100	300
Frustula	0	0	0	0	0	300
Staurastrum	300	100	100	100	10	0
Arthrodesmus	50	0	0	0	20	0
Mougeotia	0	0	0	100	0	0
Spirogyra	0	0	5,000	0	0	0
Dinobryon	500	0	0	0	20	0
Ceratium	0	0	200	40	10	0
Total	67,200	8,500	18,300	10,480	600	7,750

Table 24

Predominant Algal Genera Found in Dunham Bay and Echo Bay

Sample 9/4/72

	Number of Organisms per liter			
	Dunham Bay		Echo Bay	
	Station 2	Station 3	Station 1	Station 2
Asterionella	5,000	500	2,000	800
Fragilaria	5,000	1,100	5,000	4,000
Tabellaria	500	100	200	400
Navicula	100	60	0	100
Synedra	100	60	0	40
Pinnularia	0	0	20	20
Cymbella	0	0	100	80
Gyrosigma	0	20	0	0
Epithema	100	0	0	0
Amphora	0	0	40	60
Staurastrum	100	30	60	50
Mougeotia	0	100	0	0
Ulothrix	2,000	200	0	0
Oscillatoria	0	0	0	3,000
Stephanodiscus	0	60	20	20
Ceratium	100	20	0	0
Total	13,000	2,250	7,440	8,570

Table 25

Predominant Algal Genera Found in Dunham Bay, Echo Bay and Smith Bay

Sample 9/18/72

	Number of Organisms per liter				
	Dunham Bay		Echo Bay		Smith Bay
	Station 2	Station 3	Station 1	Station 2	Station 2
Asterionella	900	3,000	1,000	1,000	400
Fragilaria	1,500	6,000	2,000	9,000	1,000
Tabellaria	900	500	120	2,000	100
Navicula	0	0	0	500	0
Synedra	0	0	0	300	0
Pinnularia	0	0	0	100	0
Cymbella	0	0	0	100	0
Cyclotella	0	100	0	0	0
Frustula	0	0	0	100	0
Gyrosigma	0	0	0	100	0
Amphora	0	0	0	100	0
Achnanthes	0	0	0	80	60
Staurastrum	300	200	0	200	0
Spondylosium	0	0	0	300	0
Arthrodesmus	0	150	0	0	0
Cosmarium	0	0	0	80	80
Mougeotia	0	500	0	0	0
Ulothrix	0	0	0	1,000	0
Dinobryon	30	0	0	0	0
Ceratium	0	50	30	200	0
Total	3,630	10,500	3,150	15,160	1,640

in August. September samples exhibited the least amounts of algae in them. The total number of algae found in samples from Station 1, Smith Bay was less than 1000 cells/liter in samples taken on both 7/24 and 8/15/72. Although algal populations in all three bays were relatively low at that time, it is not unlikely that a copper-containing wood preservative at the dock near Station 1 had contributed to the reduction in the number of algae.

The following is a listing of the planktonic algae found in Dunham, Smith and Echo Bays, Lake George, New York, from May through September, 1972.

- Division Chlorophyta
  - Volvocaceae
    - *Gonium* Mueller
    - *Eudorina unicocca* G. M. Smith
  - Chlamydomonadaceae
    - *Chlamydonomas* Ehr.
  - Palmellaceae
    - *Sphaerocystis* Chodat
  - Ulotrichaceae
    - *Ulothrix* Kutzing
  - Micractiniaceae
    - *Golenkinia* Chodat
  - Hydrodictyaceae
    - *Pediastrum boryanum* Menegh
    - *Pediastrum* Meyen
  - Oocystaceae
    - *Pachycladon umbrinus* G. M. Smith
  - Scenedesmaceae
    - *Scenedesmus* Meyen
  - Zygnemataceae
    - *Mougeotia* Agardh
    - *Spirogyra* Link
    - *Zygnema* Agardh
  - Desmidiaceae
    - *Closterium* Nitzsch
    - *Staurastrum paradoxum* Meyen
    - *Staurastrum* Meyen
    - *Cosmarium* Corda
    - *Arthrodesmus octocornis* Ehr.
    - *Arthrodesmus* Ehr.
    - *Spondylosium* de Brebisson
- Division Chrysophyta
  - Tribonemataceae
    - *Tribonema* Derkes & Solier
  - Synuraceae
    - *Synura uvella* Ehr.
  - Ochromonadaceae
    - *Uroglenopsis americana* Lemm.
    - *Dinobryon sertularia* Ehr.
    - *Dinobryon stipitatum* Stein

Coscinodiscaceae
    Melosira Agardh
    Cyclotella Kutzing
    Stephanodiscus
Rhizosoleniaceae
    Rhizosolenia eriensis H. L. Smith
Tabellariaceae
    Tabellaria floccosa Kutz
    Tabellaria fenestrata Kutz
Fragilariaceae
    Asterionella Hassall
    Fragilaria Lyngbye
    Synedra Ehr.
Achnanthaceae
    Achnanthes
Naviculaceae
    Frustulia
    Gyrosigma
    Navicula Bory
    Pleurosigma W. Smith
    Pinnularia Ehr.
Gomphonemataceae
    Gomphonema Agardh
Cymbellaceae
    Amphora
    Cymbella Agardh
Surirellaceae
    Surirella Turpin
Ephithemiaceae
    Epithema

Division Pyrrophyta
    Gymnodiniaceae
        Gymnodinium Stein
    Ceratiaceae
        Ceratium Schrank

Division Cyanophyta
    Chroococcaceae
        Chroococcus Nageli
        Gomphosphaeria Kutzing
    Oscillatoriaceae
        Oscillatoria Vaucher
    Nostocaceae
        Anabaena Bory

Division (uncertain)
    Cryptomonadaceae
        Crytomonas Ehr.

The 50 genera listed above were identified from various samples collected from the three bays during the period under report. The predominant species, however, were few, as noted in Tables 14-25.

The data on algal populations of the three bays do not afford any significant correlation between the kind and number of algae present and the amount of oil present in each bay. The data do provide important information about the seasonal variations of major algal species present in the bays.

Figs. 23-25 have been plotted to show the response of indigenous algae to various concentrations of oil-gas mixture. The C^{14} uptake by the algae appears to initially increase at concentrations of raw fuel equal to or less than 5 ppm. However, the photosynthetic activity of the algae decreases at higher oil-gas mixture concentrations and is extremely low at a concentration of 100 ppm. The response of the indigenous algae to crankcase drainage from a two cycle outboard engine is somewhat similar in that CO_2 fixation capacity seems increasingly inhibited with increasing concentrations of the oil-gas mixture. Also, it was noted that the dark bottle counts decreased when the concentration of oil-gas mixture was 100 ppm. A number of reasons can be advanced for this behavior of the algae. These are:

1. The oil-gas mixture is not inhibitory to the ability of these algae to fix CO_2 at concentrations less than 5 ppm.
2. The addition of a small quantity of oil-gas mixture (i.e. 5 ppm) may supplement the carbon available to the algae, thereby increasing the carbon uptake by the latter. This is not to suggest that carbon is limiting but the situation is more like that of luxury uptake. It is noted that the increase in C^{14} uptake is less than 15% in all the experiments.
3. Although the oil-gas mixture at higher concentrations provides more carbon to these algae, it appears to inhibit their ability to fix CO_2.
4. It is possible that at higher concentrations the surface of the algae is coated with the oil-gas mixture which then may interfere with various biochemical functions.
5. Reflection of some of the incident light by the oil film present at the surface of the liquid, especially at higher concentrations, may affect the photosynthetic activity of the algae.
6. At higher concentrations, some of the oil-gas mixture added coats the walls of the milk dilution bottle. This may also affect the availability of light to the algae.
7. The presence of oil-gas film at the surface reduces the gas transfer from and into the sample, which may affect ^{14}C uptake by the algae.

The effects noted from these studies suggest that:

1. The crankcase drainage discharged into water by two cycle outboard engines may inhibit the ability of algae indigenous to Lake George to fix CO_2 if the hydrocarbon levels in the lake reach 3-5 ppm or more.

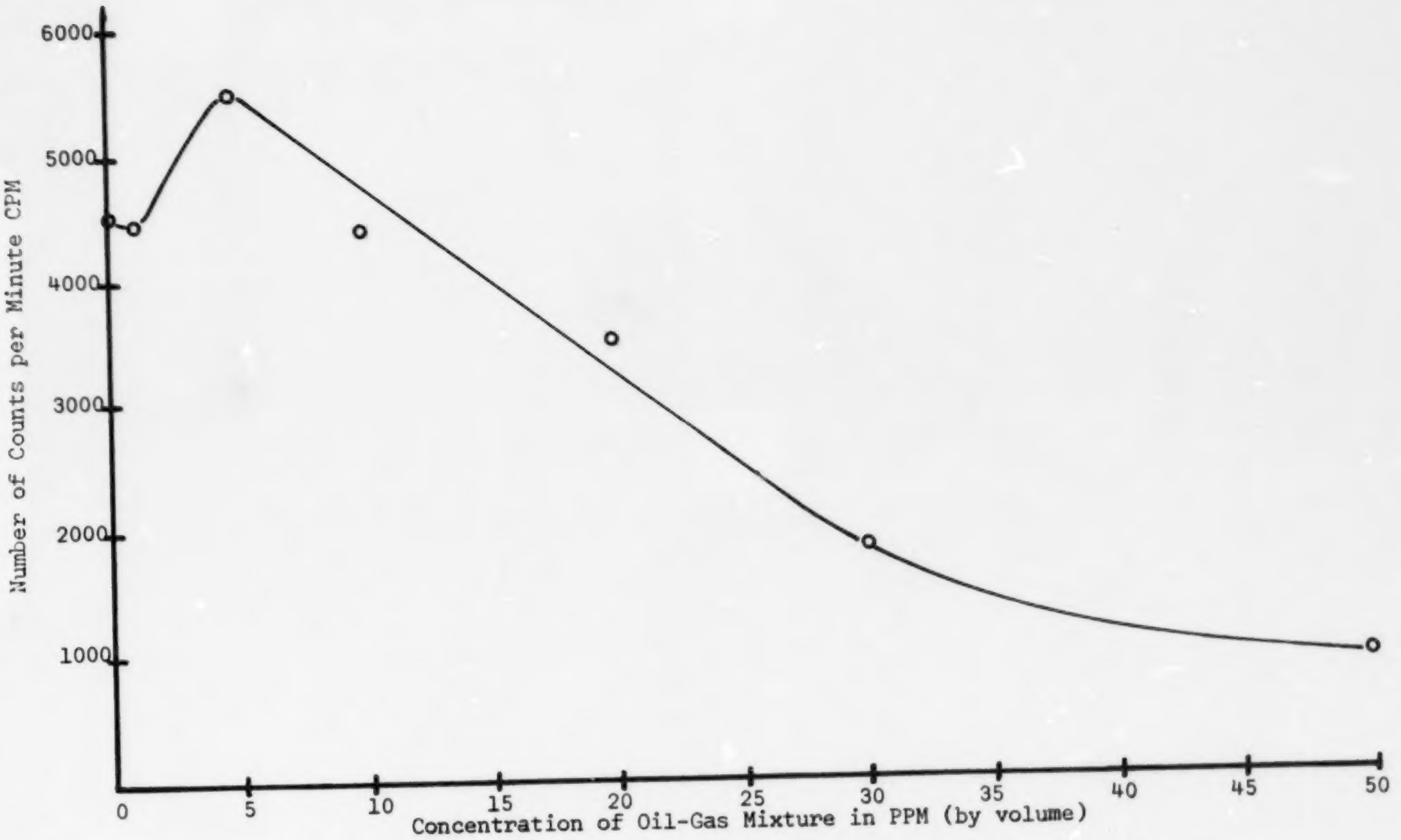

Figure 23 - Effect of Crankcase Drainage on C^{14} Uptake by Indigenous Algae
in Their Natural Population Density
Dunham Bay Sample 7/27/72

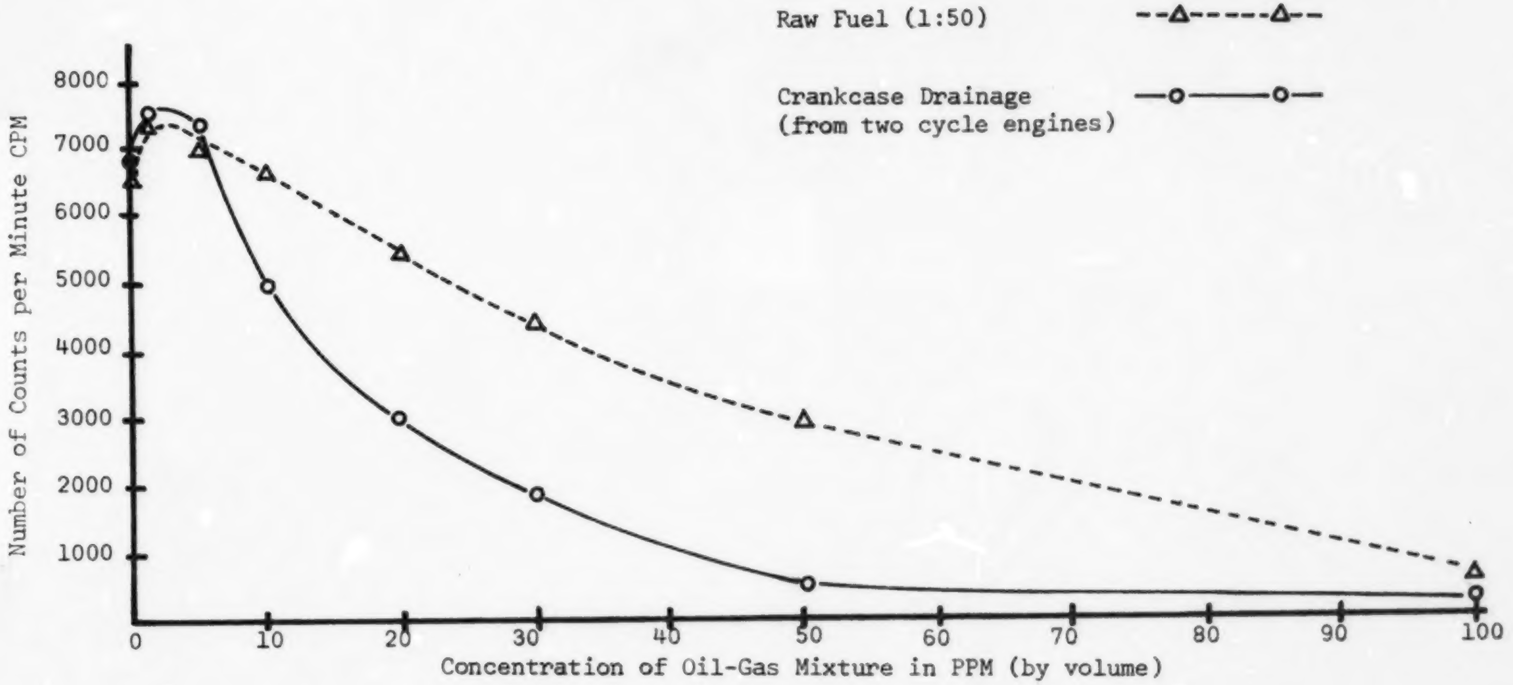

Figure 24 - Effect of Oil-Gas Mixture on C^{14} Uptake by Indigenous Algae in Their Natural Population Density

Echo Bay Sample 9/14/72

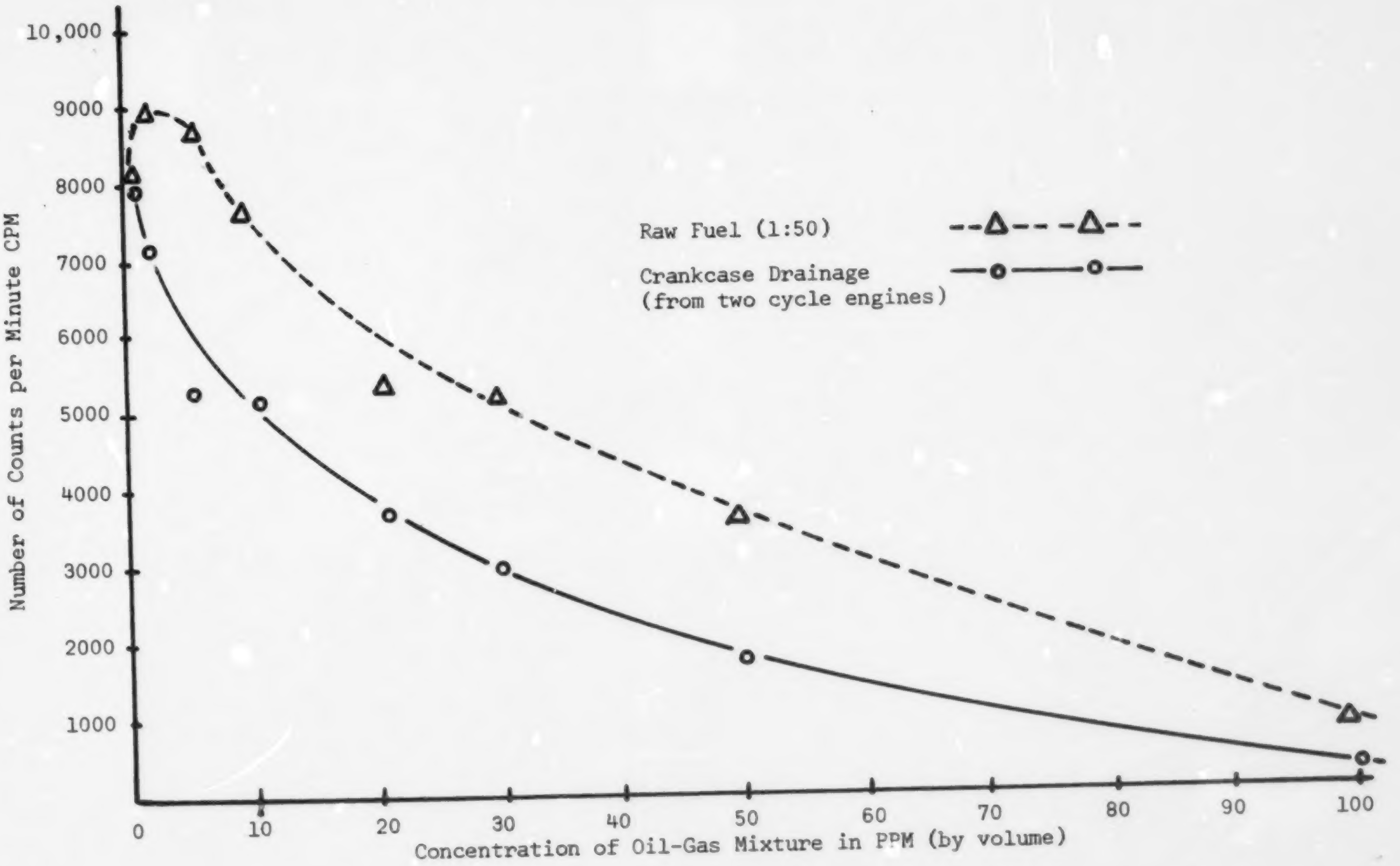

Figure 25 - Effect of Oil-Gas Mixture on C^{14} Uptake by Indigenous Algae in Their Natural Population Density

Dunham Bay Sample 9/14/72

2. Algal growth potential may be enhanced by the introduction into lake water of crankcase drainage from two cycle outboard engines to 1-3 ppm.
3. The crankcase drainage from two cycle outboard engines appears more inhibitory to the algae's rate and extent of CO_2 fixation capacity than does the raw fuel.

Data for the bioassay tests conducted on test algae in a controlled environment have been analyzed as to the effect on maximum specific growth rate of algae by the addition of water soluble extent of crankcase drainage. Mean maximum specific growth rate for replicate bottles was calculated by the EPA method (23). The computer program used for this purpose is essentially the same as employed by Sachdev (64). This has been slightly modified to include, in the computer output, the day on which maximum growth rate occurred for each bottle. The computer program, as used in this work, is listed in Appendix 1 of this report. Rensselaer's IBM 360, Model 50 computer was employed for the data analysis.

Daily absorbance readings and maximum specific growth rates for each bottle are given in Appendix 2. A summary of the results appears in Tables 26-28 and growth curves are shown in Figs. 26-28. The data on growth curves presented in summary Tables 26-28 are discussed under three headings as below.

For the sake of clarity and to avoid repetition it is added that concentrations of added carbon appearing in Tables 26-28 in mg/l and in the following discussion refer to additional concentration of carbon in the sample due to the presence of water soluble extract from crankcase drainage.

The criteria adopted for interpreting the results of bioassay tests regarding maximum specific growth rates are that values within 10% of the control indicate no effect, values more than 110% of control indicate stimulation, and values less than 90% of control indicate inhibition.

1. Maximum specific growth rate

   Microcystis aeruginosa appears to be most sensitive to water soluble extracts of crankcase drainage so far as maximum growth rate is concerned. In this case stimulation was observed when added carbon due to water soluble extract of crankcase drainage was only 1 mg/l. At 5 mg/l or more maximum growth rate decreased to a point indicating inhibition. Maximum inhibition occurred when the added carbon was 10 mg/l.

   Stimulation in the case of Selenastrum capricornutum was observed at a concentration of 35 mg/l as added carbon. At 5, 10, and 20 mg-c/l there was neither stimulation nor inhibition. Inhibition occurred only at the lowest and the highest concentration of added carbon, i.e. 1 mg/l and 120 mg/l, respectively, and about the same amount in both cases

Table 26

Growth Rates

Selenastrum capricornutum

Sample Title (1)	Mean Maximum Specific Growth Rate (2)	Day of Maximum Specific Growth Rate (average) (3)	Mean Maximum Specific Growth Rate % of Control (4)	Effect of Addition of Crankcase Drainage** (5)	Maximum Standing Crop (average)*** (6)
*0S051572IJK	1.027 ± 0.137	3		o	1.27
1S051572IJK	0.808 ± 0.290	3.33	78.68	-	1.41
5S051572IJK	1.002 ± 0.072	2.67	97.57	o	1.34
10S051572IJK	1.095 ± 0.095	3	106.62	o	1.37
20S051572IJK	0.993 ± 0.205	3	96.69	o	1.38
35S051572IJK	1.251 ± 0.079	3	121.81	+	1.31
120S051572IJK	0.780 ± 0.056	7.5	75.95	-	1.22

*0S051572IJK indicates *Selenastrum capricornutum* with 0 mg/l added carbon (control) inoculated on 05-15-72

**+ = stimulation;   - = inhibition;   o = no effect.

***Maximum standing crop is assumed to be proportional to the maximum absorbance.

Table 27

Growth Rates

Microcystis aeruginosa

Sample Title (1)	Mean Maximum Specific Growth Rate (2)	Day of Maximum Specific Growth Rate (average) (3)	Mean Maximum Specific Growth Rate % of Control (4)	Effect of Addition of Crankcase Drainage** (5)	Maximum Standing Crop (average)*** (6)
0M051572IJK	0.603 ± 0.076	3	100.1	o	1.31
*1M051572IJK	0.683 ± 0.004	3	113.27	+	1.37
5M051572 IJK	0.526 ± 0.006	3	87.23	-	1.27
10M051572IJK	0.410 ± 0.028	3	67.99	-	1.20
20M051572IJK	0.490 ± 0.123	3	81.26	-	1.20
35M051572IJK	0.508 ± 0.009	3	84.25	-	1.25
120M051572IJK	0.600 ± 0.039	5	99.50	o	1.32

*1M051572IJK indicates synthetic nutrient medium in the 1 mg/l of added carbon due to water soluble extract of crankcase drainage, inoculated with Microcystis aeruginosa on 05-15-72

**+ = stimulation; - = inhibition; o = no effect.

***Maximum standing crop is assumed to be proportional to the maximum absorbance.

Table 28

Growth Rates

Anabaena flos-aquae

Sample Title (1)	Mean Maximum Specific Growth Rate (2)	Day of Maximum Specific Growth Rate (average) (3)	Mean Maximum Specific Growth Rate % of Control (4)	Effect of Addition of Crankcase Drainage** (5)	Maximum Standing Crop (average)*** (6)
0A060972IJK	0.815 ± 0.000	4	100.0	o	0.940
1A060972IJK	0.780 ± 0.060	4	95.71	o	0.925
5A060972IJK	0.962 ± 0.092	3.67	118.04	+	0.870
10A060972IJK	0.638 ± 0.127	7	78.28	-	0.805
20A060972IJK	0.703 ± 0.128	9.5	86.26	-	0.430
30A060972IJK	0.745 ± 0.052	12	91.41	o	0.550
*60A060972IJK	0.853 ± 0.066	10	104.66	o	0.710

*60A060972IJK indicates synthetic nutrient medium with 60 mg/l of added carbon inoculated with *Anabaena flos-aquae* on 06-09-72

**+ = stimulation; - = inhibition; o = no effect.

***Maximum standing crop is assumed to be proportional to the maximum absorbance.

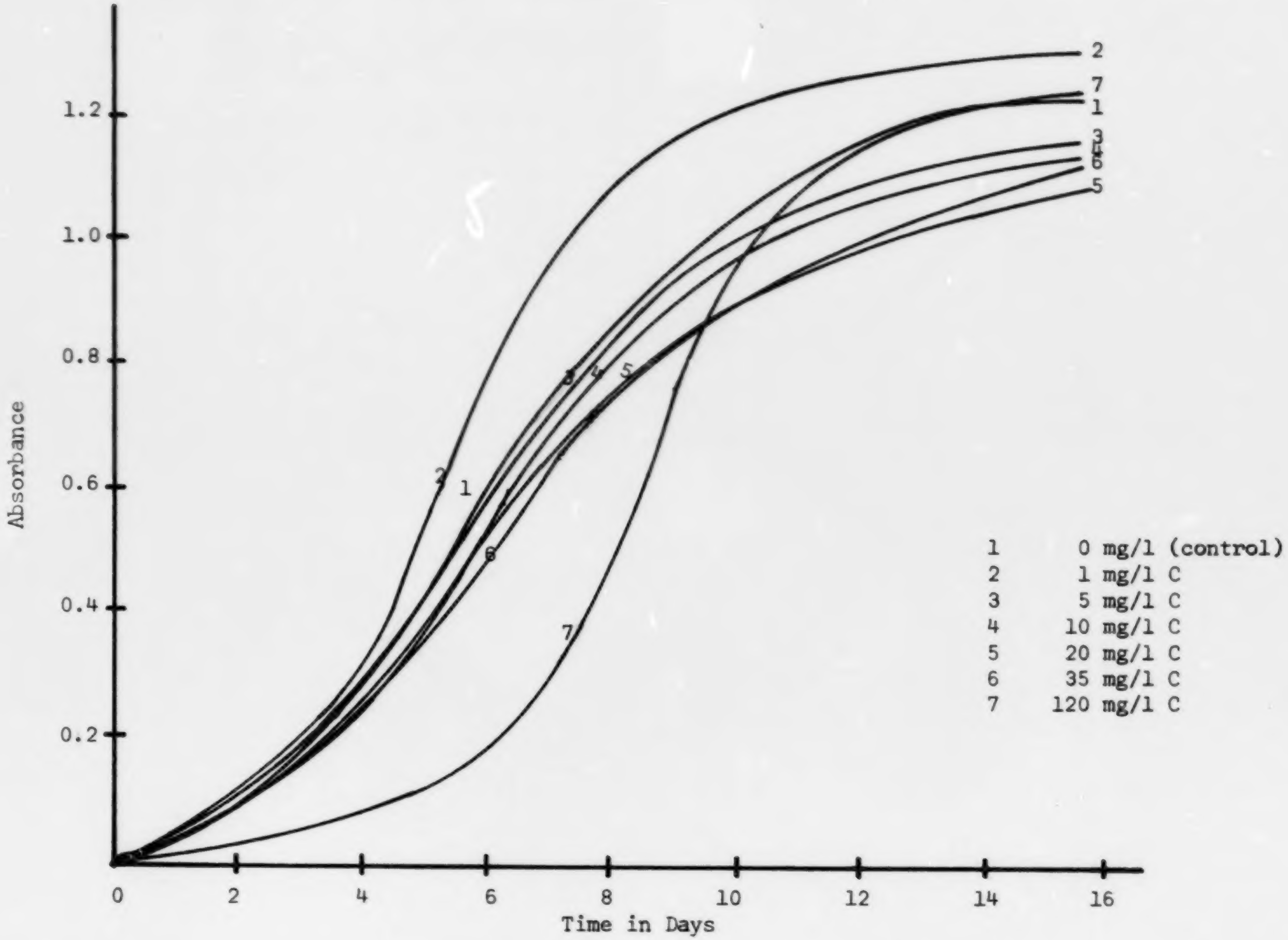

Figure 26 - Growth Curves for Microcystis aeruginosa

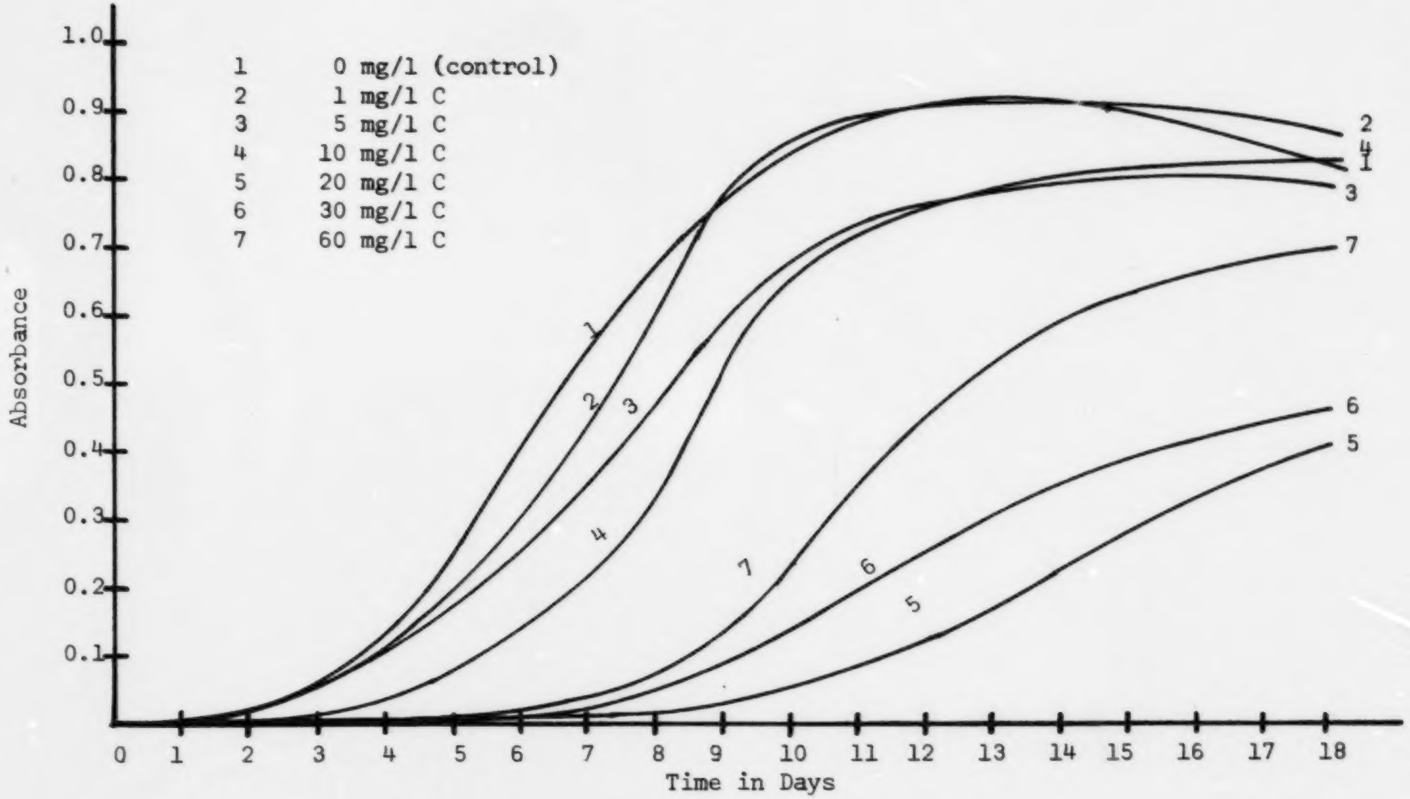

Figure 27 - Growth Curves for Anabena flos-aquae

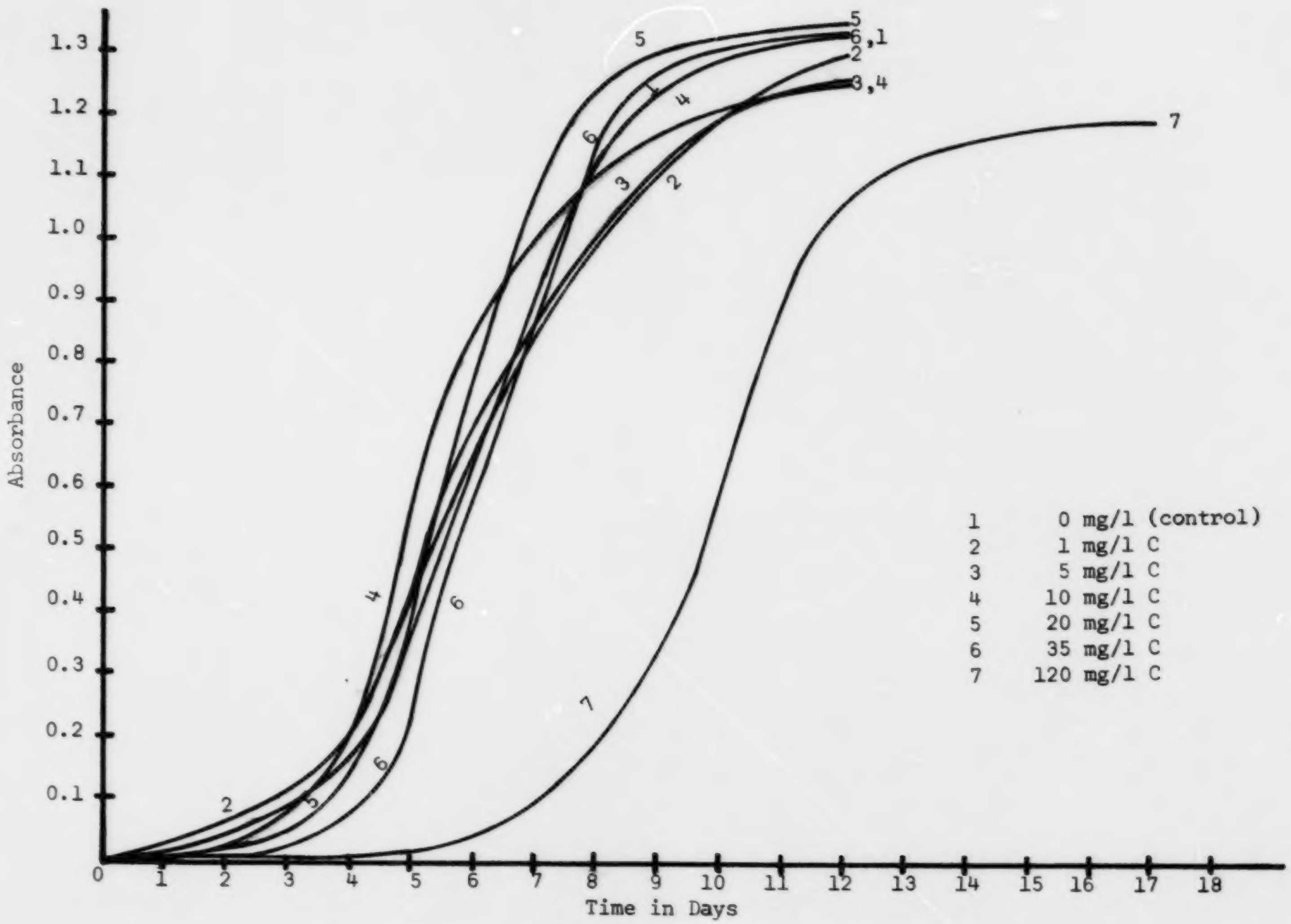

Figure 28 - Growth Curves for Selanastrum capricornutum

(23-24%). Although inhibition at 120 mg/l of added carbon may be expected, due to very high concentration of the water soluble extract in the sample, an equal amount of inhibition at 1 mg/l of added carbon is unexpected and is hard to explain.

Increase in the maximum growth rate of *Anabaena flos-aquae* occurred at a concentration of 5 mg/l of added carbon. Inhibition occurred only at 10 mg/l and 20 mg/l. Maximum inhibition of 22% was observed at 10 mg/l.

2. Maximum standing crop

Absorbance readings were taken for a maximum of 18 days. Maximum standing crop is assumed to correspond to the mean maximum absorbance readings for the replicates (Col. 6, Tables 26-28) during this period.

Microcystis aeruginosa and *Selenastrum capricornutum* show a variation from control of less than 10% in the maximum crop for any concentration of added carbon. This, therefore, indicates no effect on maximum crop as a result of addition of water soluble exhaust for crankcase drainage. In the case of *Anabaena flos-aquae*, however, the maximum crop at 20 mg/l of added carbon is as low as 46% of that of control and at 30 mg/l it is 59%. It may be added that in both cases, i.e. at 20 mg/l and 30 mg/l, the lag period, as discussed later in this section, was from 4 to 11 days (Appendix 2), and therefore, in several bottles the crop had not reached to its maximum value when absorbance measurements were discontinued. This fact, in most cases, is responsible for the low values of maximum crop mentioned above. No definite conclusion can, therefore, be drawn from these data on maximum crop for *Anabaena flos-aquae*.

3. Lag Period

Microcystis aeruginosa achieved maximum growth rate on the third day after inoculation. Even when water soluble extract was added to culture flasks, the day of maximum growth rate remained unchanged for 1, 5, 10, 20, and 35 mg/l of added carbon. For 120 mg/l, maximum growth rate occurred on the fifth day after inoculation. This clearly shows a lag period of two days for the highest concentration of added carbon.

The case with *Selenastrum capricornutum* is similar. The day of maximum growth rate for cultures with up to 35 mg/l of added carbon remained about the same as that for control. At 120 mg/l it showed an average lag period of four and one half days.

Anabaena flos-aquae appears to be affected the most so far as lag period is concerned. The lag period is as much as eight days in the case of 30 mg/l of added carbon. There is, however, no lag period in achieving maximum growth rate when added carbon due to water soluble extract from crankcase drainage is 5 mg/l or less.

In summary, therefore, the bioassay tests on test algae indicate that:

1. The result is mostly of "inhibition" or "no effect", so far as maximum specific growth rate is concerned.
2. Microcystis aeruginosa appears to be most sensitive, of the three species studied, to water soluble extract from crankcase drainage. As added carbon levels reach 5 ppm, maximum growth rate is reduced indicating inhibition.
3. Stimulation of algae has been noticed at only one concentration for each alga studied, i.e. at 1 mg/l, 5 mg/l, and 35 mg/l for Microcystis aeruginosa, Anabaena flos-aquae, and Selenastrum capricornutum, respectively.
4. Maximum standing crop does not provide any indication of the effect of water soluble extract from crankcase drainage.
5. Lag period in achieving maximum specific growth rate appears to be the best indicator of the effect of water soluble extract from crankcase drainage.
6. Anabaena flos-aquae, of the three species studied, experienced the greatest lag period. The lag period observed was from three to eight days for added carbon levels ranging from 10 to 60 mg/l.

SECTION VII - A STUDY OF THE MACRO-BENTHIC INVERTEBRATES IN THREE EMBAYMENTS OF LAKE GEORGE, NEW YORK

INTRODUCTION

The macro-benthic fauna were sampled from February through September 1972 in three bays of Lake George, New York. The purpose of this study was multiple in scope and included the following objectives:

a) Establish the taxonomy of the macro-benthic invertebrates in the littoral zone of Lake George to at least the genus level,

b) Follow the invertebrate populations through their respective seasonal fluctuations,

c) From the data obtained, develop a diversity index as an indication of water quality.

Margalef (44); $\bar{d} = -\sum_{1}^{s} \frac{ni}{n} \mathrm{Log}_2 \frac{ni}{n}$ where s = number of genera, ni = number of individuals in genera i, n = total number of organisms.

d) Interpret these results with respect to the effects of hydrocarbons from a two cycle marine engine exhaust.

Figure 1, an outline map of Lake George, shows the locations of the three bays under study.

PROCEDURES

Samples were secured from each bay station with a 6" x 6" Eckman dredge on a monthly basis with two exceptions. No data were obtained in April due to unsafe ice conditions. Also, in June biweekly samples were taken since the peak boating period apparently occurred from mid June through the July 4th weekend. Winter sampling took place through the ice.

Whenever possible, two dredge hauls were taken at each station. There were several exceptions causing population density data to be based on the average of two dredge hauls in 39 instances and on a single haul in the remaining 14 cases. Each sample was placed in a clean metal bucket and the dredge rinsed off with lake water to insure collection of all organisms. The sediments were washed using a U. S. Standard No. 30 mesh (Tyler No. 28) sieve (mesh size = 600μ) to remove silt and to reduce the sample size. Samples were washed upon collection when permissible; otherwise they were transported to shore and washed immediately. These washing procedures followed the methods suggested by Cairns and Dickson (9).

Samples obtained from February to July were picked immediately while the organisms were still alive. According to Welch (92) and others, this is the most accurate, though tedious, method. Small portions of the sample were placed in a shallow, white enamel pan under a bright light. Sufficient water was added to allow organisms to swim clear of the debris. Specimens were picked or removed using eyedroppers, forceps or a small screen dipnet. They were separated on the basis of gross morphological characteristics and placed in 70% alcohol. All samples, including those of large volume from Dunham Bay, were studied entirely. Later, the technique of Pagel (56) employing Phloxine B dye, in 70% alcohol solution, was employed. The organisms were easily separated from the sediments and the method was judged to be more efficient and less tedious than previously used techniques.

A binocular dissecting scope and a standard monocular microscope were used for the identification of the organisms. It was necessary to prepare slide mounts of the smaller organisms belonging to the Acari and Diptera groups. The specimens were boiled in an NaOH solution to soften the exoskeleton and then mounted in Turtox C Mountant. Identification was limited in most cases to the generic level. A listing of the keys utilized in identification is given on p. 304.

Acute Static Bioassays

In addition to the field studies, preliminary bioassays were conducted throughout August 1972 to obtain an approximation of toxic limits above which benthic populations would be affected. The measure chosen was the toxic lethal mean (TL_{50}) or the lethal concentration above which 50% of the test organisms were killed after a prescribed time period. The time periods chosen were 24 and 48 hours.

The selection of test organisms was based on several requirements. The organisms had to be common in the bays of Lake George to provide representative information; they had to be abundant enough to provide ample specimens and be collected easily; specimens had to be adaptable to a laboratory environment so that a healthy test population could be easily maintained; they should be sensitive to environmental stress; and, the test organisms had to be large enough to handle and to readily observe its vital signs.

Insect larvae were rejected because their life habits involve emergence and thus, test population maintenance is difficult. The common oligochaetes were not considered suitable for this particular study due to their tolerance to environmental stress. Crustaceans have been used previously by Sanders (65) and others in testing the toxicity of various chemicals. They are considered sensitive and have a complete aquatic life cycle. After much preliminary work, the amphipod *Gammarus fasciatus* and the gastropod *Amnicola limnosa* were judged appropriate for evaluation purposes.

The test organisms were obtained from the field using a Wildco dredge net which was dragged at a very low speed behind a boat. The dredge collected and concentrated plants and animal specimens while fine sediments washed through. Collection sites were chosen outside of the bays under study to prevent disturbing the study areas. Amphipods were obtained from Hulett's Landing and gastropods were collected from Northwest Bay.

Specimens were hand-picked and transferred to three 6 gallon aquaria to acclimate for at least a week prior to experimentation. The aquaria were equipped with air pump and filter. A sandy substrate was provided as was natural vegetation. Weak or injured organisms were removed to insure that only healthy specimens would be tested.

A concentrated solution of exhaust products resulting from the operation of a two cycle outboard engine was prepared. A 1971 Chrysler 9.9 HP Model 92 HD engine was run for 1/2 hour in a steel test tank. The test tank dimensions were 4' x 4' x 3' with a volume of 359 gallons. A constant speed of 3000 RPM was maintained using a tachometer. The fuel was a 50:1 mixture of Mobil Marine Gasoline to Mobil Outboard Motor Oil. Three individual runs were made to check the resulting concentrations. The tank was scrubbed with detergent and thoroughly rinsed after each run to insure that no residual exhaust products remained.

At the end of a run, subsurface samples of the test tank water were removed in a clean glass flask from a depth of 1 foot below the surface to avoid the concentrated surface film. It was felt that subsurface samples would contain the soluble or emulsified materials most likely to be found in the water column or to accumulate in sediments. The analysis procedures to determine the hydrocarbon content followed the CCl_4 extraction techniques developed by CONCAWE (2). A Beckman IR 20 Spectrophotometer was used to measure the extracted materials. The same technique has been used in other studies to obtain background hydrocarbon information from lake water samples. Calculations were based on the comparisons between readings for known hydrocarbon weights (outboard motor oil) and samples taken from the test tank.

The preparation of bioassay solutions involved the dilution of samples from the test tank with standard freshwater as recommended by Tarzwell (85). Twenty liter batches were prepared and carbon dioxide was bubbled into distilled water to obtain a carbonate system. The pH was adjusted to between 7.6 and 7.8 by bubbling air into the solution. The alkalinity of the test solution was 28.4 to 29.2 mg/l.

Clean, wide mouth, glass jars of one quart capacity were used as bioassay containers. Small measured amounts of exhaust water were pipetted into standard freshwater to make up 500 ml. Prior to pipetting, the concentrated solution was thoroughly mixed by using a mechanical shaker set at about 300 oscillations per minute for 5 minutes. After the dilution series was prepared the test jars were placed on a shaker in a similar manner to insure proper mixing.

Dissolved oxygen and temperature were recorded in each jar and 10 organisms were placed in a container for each test solution. Care was taken to insure the specimens were all of a similar size class. Amphipods between 2 and 4 mm were used and gastropods between 1 and 2 mm in shell diameter were selected. A small brass wire scoop was used to transfer the organisms to minimize injury. A glass top was placed loosely over the container. At the end of the test period, the dissolved oxygen and temperature were again recorded. The test organisms were observed for characteristic vital signs. The amphipods were judged dead if no evidence of gill movement was associated with respiration or movement in response to prodding. The gastropods required more intense scrutiny. In many cases, snails close their opercula in response to environmental stress; in addition, the opercula may remain open after death. This often made the state of death difficult to determine and in these investigations the snails were transferred to a solution of standard freshwater and left undisturbed for 24 hours. If, after this period, the opercula remained closed or a snail whose opercula was open did not close in response to prodding, the organism was judged dead. The procedures used generally followed those outlined by Patrick (57) and Tarzwell (85). Results were plotted on semi-log paper according to Warren (91) and others from which 24 and 48 hour TL_{50}'s were determined.

RESULTS

Physical and Chemical Data

Physical and chemical data are given in Tables 29-36. The dissolved oxygen (D.O.) was generally above 5.0 mg/l with two exceptions, both during May, immediately after ice went out. In both cases the deepest stations were involved, specifically Smith No. 2 (5.0 meters) and Dunham No. 3 (6.0 meters). The depth of all stations, except Dunham No. 3, was less than 7.0 meters and located within the littoral zone.

Results show that at the stations sampled, the lowest recorded bottom temperatures, 1.0 to 2.0°C, were found during February and March under the ice cover. The highest temperature was 22°C recorded in both Smith and Echo Bays in July. Similar high temperatures were reached in Dunham Bay by early September. At Dunham No. 3, a thermocline was noted from mid May to late June. Generally, the bay waters appeared to be well mixed throughout the sampling period.

Alkalinity was consistently between 20 and 25 mg/l of $CaCO_3$ at all stations except during May and late June when values were between 25 and 30 mg/l. The pH ranged between 7.0 and 7.5 with few exceptions, vis. in March pH values in Dunham Bay were between 6.48 and 6.80. This may have been due to the higher spring stream inflow carrying organic acids from the accumulated plant debris in the adjacent marsh area.

Table 29

Physical and Chemical Data

SAMPLING PERIOD	Stations						
FEBRUARY	Smith 1	Smith 2	Dunham 1	Dunham 2	Dunham 3	Echo 1	Echo 2
*Depth (meters)	1.0	4.0	3.0	--	5.0	2.0	--
Date	2/5/72	2/20/72	2/10/72	--	2/19/72	2/19/72	--
Dissolved Oxygen (mg/l)	11.0	8.0	10.5	--	10.1	11.0	--
Temperature (^{o}C)	1.0	1.0	1.5	--	1.0	1.0	--
Alkalinity (mg/l as $CaCO_3$)	--	--	--	--	--	--	--
pH	--	--	--	--	--	--	--
Secchi Disc (meters)	--	--	--	--	--	--	--

*Ice Cover

Table 30

Physical and Chemical Data

SAMPLING PERIOD	Stations						
MARCH	Smith 1	Smith 2	Dunham 1	Dunham 2	Dunham 3	Echo 1	Echo 2
*Depth (meters)	1.0	4.0	3.0	4.0	7.0	2.0	3.0
Date	3/16/72	3/16/72	3/21/72	3/21/72	3/21/72	3/25/72	3/25/72
Dissolved Oxygen (mg/l)	10.7	7.0	10.2	10.4	10.2	11.8	13.0
Temperature (^{o}C)	1.0	1.0	2.0	1.5	1.5	1.0	1.5
Alkalinity (mg/l as $CaCO_3$)	--	--	--	--	18.0	--	--
pH	7.31	7.28	6.49	6.72	6.80	7.23	7.32
Secchi Disc (meters)	**CTB	3.0	CTB	CTB	5.0	CTB	CTB

*Ice Cover
**CTB = Clear to Bottom

Table 31

Physical and Chemical Data

SAMPLING PERIOD	Stations						
MAY	Smith 1	Smith 2	Dunham 1	Dunham 2	Dunham 3	Echo 1	Echo 2
***Depth (meters)	1.0	5.0	3.0	3.5	6.5	1.0	3.0
Date	5/1/72	5/1/72	5/14/72	5/2/72	5/2/72	5/14/72	5/14/72
Dissolved Oxygen (mg/l)	9.4	5.2	7.2	8.4	4.7	11.0	9.4
Temperature (^{o}C)	6.0	4.0	8.0	6.0	4.0	7.5	5.0
Alkalinity (mg/l as $CaCO_3$)	--	28.5	--	27.2	30.8	27.0	--
pH	--	7.23	--	7.45	7.52	7.47	6.86
Secchi Disc (meters)	CTB	CTB	CTB	CTB	6.0	CTB	CTB

***Ice Out: Smith - April 24, Dunham - April 29, Echo - April 30

Table 32

Physical and Chemical Data

SAMPLING PERIOD	Stations						
JUNE (early)	Smith 1	Smith 2	Dunham 1	Dunham 2	Dunham 3	Echo 1	Echo 2
Depth (meters)	1.0	5.0	3.0	4.0	6.0	3.0	--
Date	6/6/72	6/6/72	6/7/72	6/7/72	6/7/72	6/10/72	--
Dissolved Oxygen (mg/l)	10.6	10.8	9.8	10.4	7.9	7.4	--
Temperature (^{o}C)	14.8	13.1	13.0	13.0	12.0	15.8	--
Alkalinity (mg/l as $CaCO_3$)	26.2	19.9	21.0	19.8	19.6	19.5	--
pH	7.66	7.60	7.33	7.46	7.29	7.23	--
Secchi Disc (meters)	CTB	5.5	CTB	CTB	CTB	CTB	--

Table 33

Physical and Chemical Data

SAMPLING PERIOD	Stations						
JUNE (late)	Smith 1	Smith 2	Dunham 1	Dunham 2	Dunham 3	Echo 1	Echo 2
Depth (meters)	1.0	5.0	--	2.0	6.0	2.0	3.0
Date	6/26/72	6/26/72	--	6/26/72	6/26/72	6/26/72	6/26/72
Dissolved Oxygen (mg/l)	8.4	7.6	--	8.0	7.9	7.9	8.0
Temperature (^{o}C)	19.9	18.5	--	16.8	16.0	17.5	17.0
Alkalinity (mg/l as $CaCO_3$)	30.6	27.3	--	27.0	26.5	27.6	27.2
pH	7.37	7.37	--	7.47	7.36	7.33	7.35
Secchi Disc (meters)	CTB	CTB	--	CTB	5.0M	CTB	CTB

Table 34

Physical and Chemical Data

SAMPLING PERIOD	Stations						
JULY	Smith 1	Smith 2	Dunham 1	Dunham 2	Dunham 3	Echo 1	Echo 2
Depth (meters)	1.0	5.0	--	2.0	6.5	2.0	3.0
Date	7/13/72	7/13/72	--	7/14/72	7/14/72	7/14/72	7/14/72
Dissolved Oxygen (mg/l)	8.9	8.4	--	9.0	9.0	8.1	8.5
Temperature (^{o}C)	21.5	22.0	--	21.0	18.0	22.0	21.0
Alkalinity (mg/l as $CaCO_3$)	23.0	22.4	--	22.4	21.6	21.6	23.0
pH	7.36	7.45	--	7.36	7.19	7.21	7.18
Secchi Disc (meters)	CTB	CTB	--	CTB	CTB	CTB	CTB

Table 35

Physical and Chemical Data

SAMPLING PERIOD AUGUST	Smith 1	Smith 2	Dunham 1	Dunham 2	Dunham 3	Echo 1	Echo 2
Depth (meters)	1.0	5.0	--	3.0	6.0	3.0	3.0
Date	8/11/72	8/11/72	--	8/16/72	8/16/72	8/15/72	8/15/72
Dissolved Oxygen (mg/l)	7.4	7.3	--	8.6	8.6	8.0	8.6
Temperature (°C)	21.0	21.5	--	21.5	20.0	22.0	21.5
Alkalinity (mg/l as $CaCO_3$)	21.0	23.0	--	23.6	23.0	25.1	22.4
pH	7.38	7.59	--	7.42	7.20	7.45	7.62
Secchi Disc (meters)	CTB	CTB	--	CTB	CTB	CTB	CTB

Table 36

Physical and Chemical Data

SAMPLING PERIOD SEPTEMBER	Smith 1	Smith 2	Dunham 1	Dunham 2	Dunham 3	Echo 1	Echo 2
Depth (meters)	1.0	5.0	--	3.0	6.0	2.0	3.0
Date	9/4/72	9/4/72	--	9/4/72	9/4/72	9/4/72	9/4/72
Dissolved Oxygen (mg/l)	5.8	6.2	--	8.1	8.2	7.9	8.7
Temperature (°C)	21.0	21.7	--	21.8	21.8	22.1	22.1
Alkalinity (mg/l as $CaCO_3$)	25.4	23.0	--	23.4	23.7	23.3	22.4
pH	7.52	7.50	--	7.4	7.38	7.32	7.40
Secchi Disc (meters)	CTB	CTB	--	CTB	5.5	CTB	CTB

Secchi disc readings were between 3 to 5 meters and at most stations the bottom was clearly visible. Periodically at the deeper stations, especially Dunham No. 3, visibility was limited. In such cases, a higher phytoplankton population appeared to be the cause.

The bottom sediments varied considerably among the three bays studied. Dunham Bay sediments were primarily silt and plant debris; Echo Bay sediments were principally clay and some fine sand with a dense mat of roots from submerged plants which effectively bind the substrate together; Smith Bay sediments varied from sand at Station No. 1 to more silt and clay at Station No. 2. Table 37 represents the approximate amounts of silt, sand, clay and plant debris in the sediments sampled. Table 38 shows the average penetration of the dredge at each station.

Aquatic Vegetation

Echo Bay supported several species of aquatic vegetation with varying density. Table 39 lists the species identified and their respective distribution. *Potamogeton Robbinsii* was common to all bays. *Nitella* Spp. were limited to the deeper waters of Smith and Dunham Bays and some were observed only at shallow water stations. One species of water milfoil, *Myriophyllum alterniflorum*, was identified from all stations but it was not abundant.

Benthic Macroinvertebrates

Over 100 taxonomic groups have been identified from the samples. Table 40 contains a list of the fauna identified and shows the distribution of organisms among the bays studied. In general, over 50 taxa were represented at each station. Echo Bay Stations 1 and 2 were the lowest with 50 and 48 different taxa being identified, respectively. The greatest faunal variation was found at Dunham Bay No. 2 with 72 different taxonomic groups being represented.

The number of taxa identified from Dunham, Smith and Echo Bays were 91, 83 and 62, respectively. The total taxa identified from all samples was 108. Most taxa were common to Smith and Dunham Bay; however, many were absent in Echo Bay. Where adequate keys were available, species were identified; yet, in many cases identification was possible only to the generic level. At least one representative of each major class of invertebrate common to freshwaters was identified from each station. Of considerable importance was the cosmopolitan nature of the amphipods, isopods and various insect nymphs. At least 46 of the 108 taxa identified were common to all three bays and many were found at all stations.

The average number of different taxa identified from each sample was considerably less than the total. Figure 29 illustrates the average number of taxa found in a single dredge haul at each station. Attention should be directed to the corresponding number of taxa being nearly proportionate to the distribution indicated in Table 40.

Table 37

Estimated Substrate Compositions (%)

Material	Smith 1	Smith 2	Dunham 1	Dunham 2	Dunham 3	Echo 1	Echo 2
Organic Debris	--	20	50	60	30	10	20
Silt (fine sediments)	20	40	50	40	70	10	20
Clay	--	--	--	--	--	60	40
Sand	80	40	--	--	--	20	20

Table 38

Average Dredge Penetration

Average Dredge Penetration	Smith 1	Smith 2	Dunham 1	Dunham 2	Dunham 3	Echo 1	Echo 2
5 cm	X						
8 cm		X				X	
10 cm							X
15 cm			X	X	X		

Table 39

List of Aquatic Plants* Identified from Each Bay

	Station**						
	Smith 1	Smith 2	Dunham 1	Dunham 2	Dunham 3	Echo 1	Echo 2
Characeae							
Nitella flexilis		C			C		
Nitella hyalina		C			C		
Isoetaceae							
Isotes Tuckermanii A. Br	C					C	
Najadaceae							
Potamogeton amplifolius Tuckerman			C				C
Potamogeton Richardsonii (Benn.) Rydb.			C				
Potamogeton gramineus var myriophyllus Robbins			C	C			
Potamogeton Robbinsii Oakes		C	C	C			C
Hydrocharitaceae							
Elodea canadensis (Michx.) Phanchon	C		C				C
Cyperaceae							
Eleocharis acicularis (L.) R & S	C					C	
Eriocaulaceae							
Eriocaulon septangulare With.	C					C	
Pontederiaceae							
Pontederia cordata forma *taenia* Fassett						C	
Ceratophyllaceae							
Ceratophyllum demersum L.			C			C	C
Hippuridaceae							
Hippuris vulgaris L.	C		C			C	C
Myriophyllum alterniflorum Pugsley	C	C	C	C	C	C	C
Myriophyllum tenellum Bigel	C					C	
Myriophyllum Farwellii Marong				C	C		

*See page 304, Identification Source C.
**C = Common

Table 40

List of Benthic Fauna Identified from Each Bay*

		Station**						
	Taxa Identified	Smith 1	Smith 2	Dunham 1	Dunham 2	Dunham 3	Echo 1	Echo 2
	COELENTERATA (b, g)							
1.	*Hydra americana*, Hyman	C	C	C	C	C	C	C
	TURBELLARIA (b, g)							
	Planariidae							
2.	*Dugesia tigrina*, Girard	C	C	C	C	C	C	C
	GORDIIA (b, g)							
	Gordiidae							
	Gordius sp., Linneaus	C	C	C	C	C	C	C
	OLIGOCHAETA (b, g)							
	Naididae							
4.	*Chaetogaster* sp. K, Von Baer	P						
5.	*Pristina bilongata*, Chan		P			P		
6.	*Pristina osborni*, Walton	C	C	C	C	C	C	C
7.	*Pristina breviseta*, Bourne	C	C	C	C	P	C	
8.	*Dero* sp., Okan							P
9.	*Stylaria fossularis*, Leidy	C	C		C	C	C	C
10.	*Nais* sp., Muller	C	C		P			
	Haplotaxidae							
11.	*Haplotaxis* sp., Hoffmeister	C	C	C	C	C	C	C
	Lumbricidae							
12.	*Eiseniella* sp., Michaelse	C	C	C	C	C	C	C
	Enchytraeidae							
13.	*Henlea* sp., Michaelsen	C	C	C	C	C	C	C
14.	*Enchytraeus* sp., Henle	C	C		C	C	C	C

*Identification sources noted after each major taxa, see page 304
**C = Common, P = Present, A = Abundant

Table 40 (continued)

		Station						
	Taxa Identified	Smith 1	Smith 2	Dunham 1	Dunham 2	Dunham 3	Echo 1	Echo 2
	OLIGOCHAETA (cont)							
	Tubifieidae							
15.	*Limnodrilus* sp., Claparede	P	C	C	C	C	P	P
16.	*Tubifex tubifex*, O. F. Muller	A	C		C	C		C
	HIRUDINEA (b, g)							
	Glossiphoniidae							
17.	*Helobdella* sp., E. Blanchard		C	C	C	C		C
	ISOPODA (a, b, g)							
	Aselidae							
18.	*Asellus communis*, Say		C	C	C	C	C	
	AMPHIPODA (a, b, g)							
	Talitridae							
19.	*Hyalella azteca*, Saussure	C	C	C	C	C	C	C
	Gammaridae							
20.	*Gammarus fasciatus*, Say	C	C	C	C	C	C	C
	EMPHEMEROPTERA (b, f, g, h)							
	Caenidae							
21.	*Caenis* sp., Stephens	C	C	C	C	C	C	C
	Ephemerellidae							
22.	*Ephemarella* sp., Walsh	C	C		C		C	C
	Siphonuridae							
23.	*Ameletus* sp., Eaton					P		
24.	*Centroptilum* sp., Eaton	P			P			
	NEUROPTERA (b, g, h)							
	Sialidae							
25.	*Sialis* sp., Latreille	P	C	P	P	P	P	C

Table 40 (continued)

		Station						
	Taxa Identified	Smith 1	Smith 2	Dunham 1	Dunham 2	Dunham 3	Echo 1	Echo 2
	ODONATA (b, g, h)							
	Agrionidae							
26.	*Anomalogrion* sp., Selys	C	C		C		C	C
27.	*Enallagma* sp., Charpentier	C	C					
	Libellulidae							
28.	*Tetragoneuria* sp., Hagen	P***		C				
	COLEOPTERA (b, g, h)							
	Gyrinidae							
29.	*Dineutus* sp., MacLeay				P			
	Haliplidae							
30.	*Peltodytes* sp., Regimbart	P						
31.	*Haliplus* sp., Latreille	P					P	
	TRICOPTERA (b, g, h)							
	Hydroptilidae							
32.	*Oxyethira* sp., Elton		P					
	Psychomyiidae							
33.	*Phylocentropus* sp., Banks		C		C			
34.	*Polycentropus* sp., Curtis	C	C	C	C	C	C	C
35.	*Psychomyiid* *Genus* *B*	C	C	C	C			
	Leptoceridae							
36.	*Leptocerus* *americanus*, Banks		C	C	C	C	C	
37.	*Leptocella* sp., Banks	C	C	C	C	C	C	C
38.	*Triaenodes* sp., McLaehlan		C	C	C		C	
	LEPIDOPTERA (b, g, h)							
39.	*Nyphyla* sp. (= Poraponyx), Schrank			P			P	P

***Observed emerging as pre-adults, but never found in samples

Table 40 (continued)

	Taxa Identified	Smith 1	Smith 2	Dunham 1	Dunham 2	Dunham 3	Echo 1	Echo 2
		Station						
	DIPTERA (b, d, e, h, i)							
	Chironomidae							
	Tanypodinae							
40.	*Anatopynia* (*Psectrotanypus*) sp., Johannsen		P					P
41.	*Tanypus* sp., Meigen		P					
42.	*Procladius* sp., (Skuse) Edwards	P	C	C	C	C	C	C
43.	*Clinotanypus* sp., Kieffer	C	C	C	C	C		
44.	*Coelotanypus* sp., Kieffer		P	P	P			
45.	*Pentaneura* *flavifrons*, Johannsen			P				
46.	*Pentaneura* *pilosela*, Loew		P	P				
47.	*Pentaneura* *monilis*, Linnaeus	C	C	C	C	C	C	C
48.	*Pentaneura* *carnea*, Fabricius		C	P	P			P
49.	*Pentaneura* *declarata* Malloch		P	P				
	Chironominae							
50.	*Pseudochironomus* *richardsoni*, Malloch		C		C	C		
51.	*Chironomrus* (*Cryptochironomus*) *stylifera*, Johannse Var a.	C		C	C	C	C	C
52.	*Chironomus* (*Cryptochironomus*) *parilis*, Walker				P		P	
53.	*Chironomus* (*Cryptochironomus*) nais (?)	P			P			
54.	*Chironomus* (*Cryptochironomus*) *abortivus*, (Harnischia), Malloch	C	C	C	C	C		C

Table 40 (continued)

		Station						
	Taxa Identified	Smith 1	Smith 2	Dunham 1	Dunham 2	Dunham 3	Echo 1	Echo 2
55.	*Chironomus* *(Stenochironomus)* *exquisitus*, Mitchell(?)	P			P	P		P
56.	*Chironomus* *(Endochironomus)* *dimorphus*, Malloch			C	C	C		
57.	*Chironomus* *(Glyptotendipes)* *senilis* n.s.p.				P			
58.	*Chironomus* *(Chironomus)* sp. (?)	C	C	C	C	C	C	
59.	*Chironomus* *(Xenochironomus)* *xenolabis*, Kieffer				P			
60.	*Chironomus* *(Kiefferalus)*, Johannsen					C		
61.	*Chironomus* *(Limnochironomus)* *modestus*, Say		C		C	C		C
62.	*Chironomus* *(Limnochironomus)* *tenuicaudatus*, Malloch		C	C		C		
63.	*Chironomus* *(Polypedilum)* sp., Kieffer	C	C	C	C	C	C	C
64.	*Phaenopsectra* *(Pentapedilum)* sp., Kieffer			P				
65.	*Zavrelia* *(Tanytarsus)* sp., Kieffer (?)	P						
66.	*Tanytarsus* *(Calopsectra)* *dissimilas*, Johannsen	C	C	C	C	C	C	C
67.	*Tanytarsus* *(Calopsectra)* *exigous*, Johannsen				P			

Table 40 (continued)

	Taxa Identified	Station Smith 1	Smith 2	Dunham 1	Dunham 2	Dunham 3	Echo 1	Echo 2
68.	*Tanytarsus* *(Calopsectra)* *gregarius*, Kieffer			C	C		C	
69.	*Tanytarsus* *(Microspectra)* *deflectus*, Johannsen	C			C			
70.	*Tanytarsus* *(Microspectra)* *dives*, Johannsen	C	C	C	C			
71.	*Tanytarsus* *(Senslat)* sp. J. (?)	C	C	C				
	Orthocladimae							
72.	*Coryneura* sp., Winnertz	P						
73.	*Brillia* sp., Kieffer			P		P	P	P
74.	*Cricotopus* *trifasiatus*, Panzer	P	C					
75.	*Trichocladius* *(Spaniotoma)* *senex*, Kieffer	C	C	C	C	C	C	C
76.	*Psectrocladius* *(Spaniotoma)* *simulans*, Johannsen	P			P		P	
77.	*Psectrocladius* *(Spaniotoma)* sp. A, Kieffer	P	P					
	Ceratopodinae							
78.	*Cuilicoides* sp., Latreille							P
79.	*Palpomyla* sp., Mcgerla	C	C	C	C	C	C	C
80.	*Palpomyla* *tibialis*, Meigen		C			C		C
	Culicidae							
	Chaoborinae							
81.	*Chaeoborous* sp., Lichtenstein					P		
	ACARI (b, h)							
	Limnesiidae							
82.	*Limnesia* sp., Koch	P		P	P	P		P

Table 40 (continued)

		Station						
	Taxa Identified	Smith 1	Smith 2	Dunham 1	Dunham 2	Dunham 3	Echo 1	Echo 2
	Lebertiidae							
83.	*Frontipoda* sp., Kocnilxe		P					
84.	*Oxus* sp., Kramer	P	P		P	P	P	
	Mideopsidae							
85.	*Mideopsis* sp., Neuman				P			
	Pionidae							
86.	*Hydrochoreutes ungulatus*, Koch	P		P	P	P		
87.	*Forelia* sp., Haller					P		
	Unionicolidae							
88.	*Unionicola* sp., Halderman				P	P	P	
	Axonopsidae							
89.	*Albia* sp., Thon				P			
	Eylaidae							
90.	*Eylais* sp., Latreille					P		
	Arrenuridae							
91.	*Arrenurus* sp., Duges		P	P	P	P	P	P
	Hydryphantidae							
92.	*Hydryphantes* sp., Koch			P	P	P		P
	Hydrochnidae							
93.	*Hydrachna* sp., Muller	P	P				P	P
	Hydrodromidae							
94.	*Hydrodroma* sp., Koch (= Diplodontus Duge)					P		
	GASTROPODA (b, g, h)							
	Physidae							
95.	*Physa* sp., Draparnaud	P			P	P	P	P

Table 40 (continued)

	Taxa Identified	Station Smith 1	Smith 2	Dunham 1	Dunham 2	Dunham 3	Echo 1	Echo 2
	Lymnacidae							
96.	*Lymnaea* sp., Lamarck	P					P	
	Planorbidae							
97.	*Gyraulus deflectus*, Say	P			P	P	P	
98.	*Gyraulus altissimus*, Baker	C	C	C	C	C	C	
99.	*Heliosoma* sp., Swainson	C	C		C	C	C	C
	Ancylidae							
100.	*Ferrissia* sp., Walker			P		P		
	Viviparidae							
101.	*Vipiparus* sp., Montfort	P	P	P	P	P	C	C
102.	*Campeloma* sp., Rafinesque		P			P	P	P
	Valvatidae							
103.	*Valvata tricarinata*, Say	C	C	C	C	C		
104.	*Valvata* sp., Muller	P	P		P			
	Bulimidae							
105.	*Amnicola limnosa*, Say	C	C	C	C	C	C	C
	PELECYPODA (b, g, h)							
	Margaritiferidae							
106.	*Margaritifera margaritifera*, Linne		P	P	P	P	P	P
	Sphaeriidae							
107.	*Sphaerium* sp., Scopoli	P	P	P	P	P		
108.	*Pisidium* sp., Pfeiffer	C	C	C	C	C	C	C
	Total Taxa found per station	62	67	56	72	65	50	48
	Total Taxa found per Bay	83		91			62	
	Total Taxa all Bays				108			

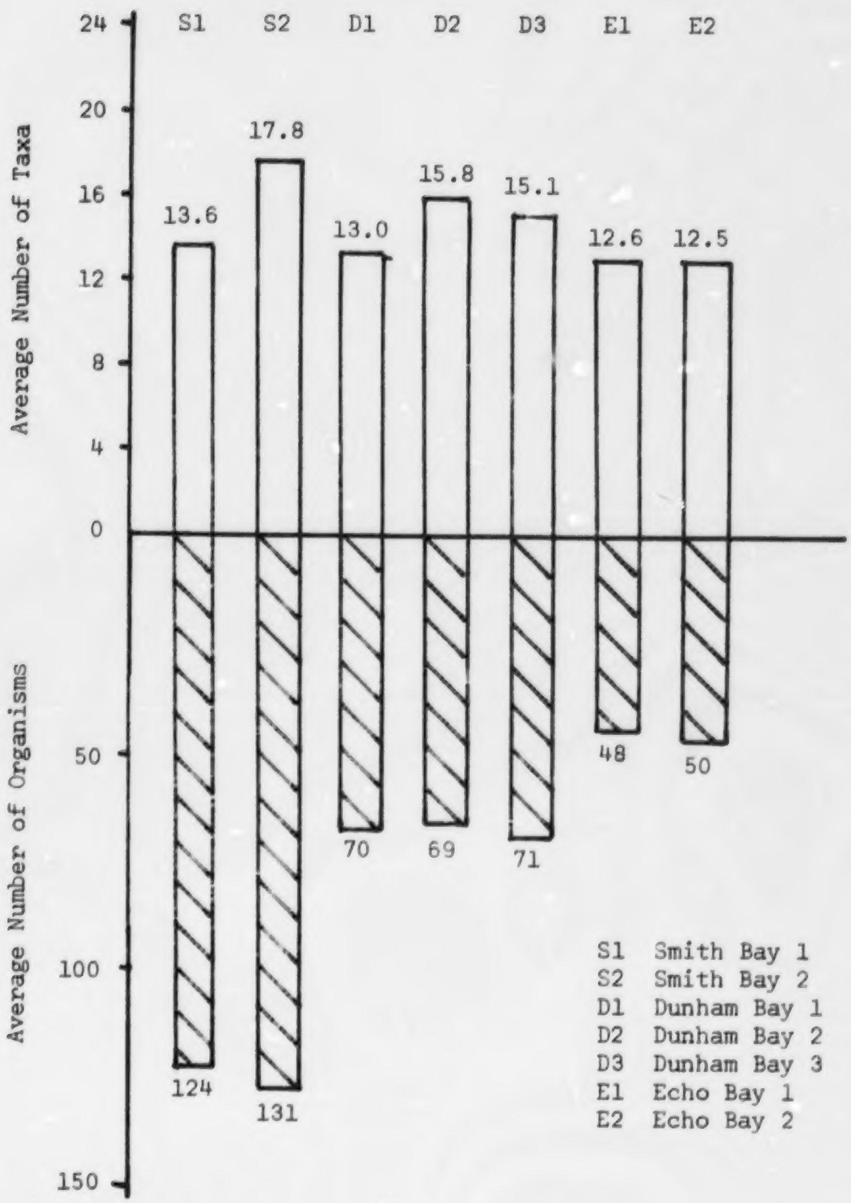

Figure 29 - Comparison of Average Number of Taxa and Average Number of Organisms per Dredge Haul for Each Station

The distribution of organisms varied considerably at all stations on a monthly basis. Tables 41-48 contain tabulations of the number of organisms per square meter at each station throughout the sampling period. To obtain these values the results of two dredge hauls (39 instances) were added and multiplied by 22. If data for only one haul was available (14 instances) the results were multiplied by 43. These factors are based on the dredge sample area of 36 square inches or 0.0238 square meters.

Figure 29 also illustrates the average number of organisms per dredge haul at each station. Smith Bay stations had the highest standing crop followed by those from Dunham Bay and Echo Bay, respectively. The densest populations were at Smith No. 2 when 12,151 organisms per square meter were found in May 1972. Smith No. 1 had a population high of 10,704 organisms per square meter in the September 1972 samples. In the former case, dipteran larvae were the most common organisms; in the latter, oligochaetes (especially _Tubifex_ sp.) were especially abundant. The lowest population density occurred at Dunham Bay Station No. 2 in late June (i.e. 882 organisms per square meter). In February, Dunham Bay No. 3 had 989 organisms per square meter.

Figures 30-32 illustrate the variations in dominant taxonomic groups throughout the sampling period. The early dominance of dipterans (February through May) followed by increased numbers during the summer of oligochaetes, gastropods and pelecypods is quite clear. One should note the three to tenfold increases of amphipods at several stations in May 1972, and the increase of isopods at Dunham No. 3 in late June. These high population densities of crustaceans were comprised of numerous small individuals. In the case of the isopods, the female adults examined in the same samples carried many eggs.

In general, Smith Bay Station 2 showed the highest population numbers. Population densities of macroinvertebrates appeared maximum in May (Echo Bay) or early June (Smith and Dunham Bays) followed by a sharp decline in late June or early July 1972. Insect nymphs from Empheroptera, Tricoptera, Neuroptera and Odonata had virtually disappeared by the end of June. These total population densities began to increase again at all stations during August and September. At the end of September Tricoptera nymphs reappeared in most of the bays.

The abundance of individual genera of dipteran larvae varied considerably from month to month and among the bays. The genus _Procladius_ was common in most samples and in May, June and July, _Polypedilium_ was found at most stations. Members of the genus _Tanytarsus_ were especially common in March, August and September. Station No. 2 at Smith Bay and No. 3 at Dunham Bay, the deepest stations studied, seemed to consistently support the largest and

Table 41

Density of Dominant Benthic Macroinvertebrate Orders

(number of organisms per meter^2)

SAMPLING PERIOD	Stations						
FEBRUARY	Smith 1	Smith 2	Dunham 1	Dunham 2	Dunham 3	Echo 1	Echo 2
Oligochaeta	474	1205	43			344	
Amphipoda	107	560	301		215	129	
Isopoda			129				
Pelecypoda	86						
Gastropoda	86	129	43		43	387	
Diptera	776	4000	730		645	301	
Tricoptera		172	86			343	
Ephemeroptera	86	258	43		86	86	
Neuroptera	43	387					
Odonata			43				
Others	64						
TOTAL	1722	6711	1418		989	1590	

Table 42

Density of Dominant Benthic Macroinvertebrate Orders

(number of Organisms per meter^2)

SAMPLING PERIOD	Stations						
MARCH	Smith 1	Smith 2	Dunham 1	Dunham 2	Dunham 3	Echo 1	Echo 2
Oligochaeta	840	86	43	86	43	344	100
Amphipoda	258	1060	344	308	474	155	116
Isopoda		22	280				
Pelecypoda		86	43				28
Gastropoda	602	129	114		108	1250	1160
Diptera	1630	4860	1210	1160	689	645	344
Tricoptera		43	43		43	64	14
Ephemeroptera	124	172	22		22	86	28
Neuroptera		129		43	22		
Odonata			22			22	14
Others		22			64	43	72
TOTAL	3454	6609	2121	1597	1465	2609	1876

Table 43

Density of Dominant Benthic Macroinvertebrate Orders

(number of organisms per meter^2)

SAMPLING PERIOD	Stations						
MAY	Smith 1	Smith 2	Dunham 1	Dunham 2	Dunham 3	Echo 1	Echo 2
Oligochaeta	1290	86	43	365	64	453	645
Amphipoda	129	4480	237	1035	580	1763	1161
Isopoda			22			157	
Pelecypoda			108	64	43	129	22
Gastropoda	1420	108	64	194	355	560	474
Diptera	1161	6270	903	1380	2230	558	774
Tricoptera	43	172		129		22	86
Ephemeroptera	152	818		43		387	22
Neuroptera		195					86
Odonata	22			43			
Others	43	22	194	43	129	43	43
TOTAL	4260	12151	1571	3296	3390	4072	3313

Table 44

Density of Dominant Benthic Macroinvertebrate Orders

(number of organisms per meter^2)

SAMPLING PERIOD	Stations						
JUNE (early)	Smith 1	Smith 2	Dunham 1	Dunham 2	Dunham 3	Echo 1	Echo 2
Oligochaeta	3700	86	22	108		280	539
Amphipoda	108	430	150	108		64	194
Isopoda		43	22				
Pelecypoda	86	43	172	172		22	
Gastropoda	1680	603		430		988	625
Diptera	688	646	732	215		301	344
Tricoptera		129	22	129			22
Ephemeroptera	86	43				86	
Neuroptera	22						43
Odonata	43	43	22				
Others			64	150		85	43
TOTAL	6413	2066	1206	1312		1826	1810

Table 45

Density of Dominant Benthic Macroinvertebrate Orders

(number of organisms per meter^2)

SAMPLING PERIOD	Stations						
JUNE (late)	Smith 1	Smith 2	Dunham 1	Dunham 2	Dunham 3	Echo 1	Echo 2
Oligochaeta	5410	108	65	150	215	323	452
Amphipoda	22	880	454	65	238	22	86
Isopoda			3500		22		
Pelecypoda	65		580	65	580	22	22
Gastropoda	1270	278	150	301	278	560	815
Diptera	194	1410	510	215	3000	172	150
Tricoptera		236	65	43	86	43	86
Ephemeroptera	86	409				65	
Neuroptera	22	108					
Odonata							22
Others		43		65	108	43	43
TOTAL	7069	3472	5324	904	4527	1250	1676

Table 46

Density of Dominant Benthic Macroinvertebrate Orders

(number of organisms per meter^2)

SAMPLING PERIOD	Stations						
JULY	Smith 1	Smith 2	Dunham 1	Dunham 2	Dunham 3	Echo 1	Echo 2
Oligochaeta	4150	280	22	840	172	648	408
Amphipoda	43	172	387	129	236	43	65
Isopoda		236	301	129			
Pelecypoda	64	258	365	419	325	151	108
Gastropoda	730	602	194	539	135	560	990
Diptera	86	925	1080	508	1510	193	151
Tricoptera	22	22	43	129	86		22
Ephemeroptera	22	65				22	
Neuroptera		22			22		
Odonata	22	22					
Others	65	86	22	172	151	43	
TOTAL	5204	2690	2414	2865	2637	1660	1744

Table 47

Density of Dominant Benthic Macroinvertebrate Orders

(number of organisms per meter^2)

SAMPLING PERIOD	Stations						
AUGUST	Smith 1	Smith 2	Dunham 1	Dunham 2	Dunham 3	Echo 1	Echo 2
Oligochaeta	4730	815	430	1570	1720	452	1010
Amphipoda	215	1140	1785	744	172	43	344
Isopoda		65	409		258	43	
Pelecypoda	22	236	1420	1680	1335	43	193
Gastropoda	1308	387	268	279	183	667	751
Diptera	108	1030	1462	1100	1465	193	151
Tricoptera		65	65	43			43
Ephemeroptera			22				
Neuroptera	43					22	22
Odonata							
Others	108	236	450	494	172	65	65
TOTAL	6534	3974	6289	5932	5305	1528	2579

Table 48

Density of Dominant Benthic Macroinvertebrate Orders

(number of organisms per meter^2)

SAMPLING PERIOD	Stations						
SEPTEMBER	Smith 1	Smith 2	Dunham 1	Dunham 2	Dunham 3	Echo 1	Echo 2
Oligochaeta	6880	2363	730	2620	1510	904	1935
Amphipoda	258	387	1980	645	815		172
Isopoda			1248		43		
Pelecypoda	43	86	344	903	1120	86	603
Gastropoda	3050	162	172	301	129	602	772
Diptera	43	2105	1460	686	816	301	86
Tricoptera	43	258	129	215		129	43
Ephemeroptera							
Neuroptera		86					
Odonata							
Others	387	301	215	645	730	344	387
TOTAL	10704	5748	6278	6015	5163	2366	3998

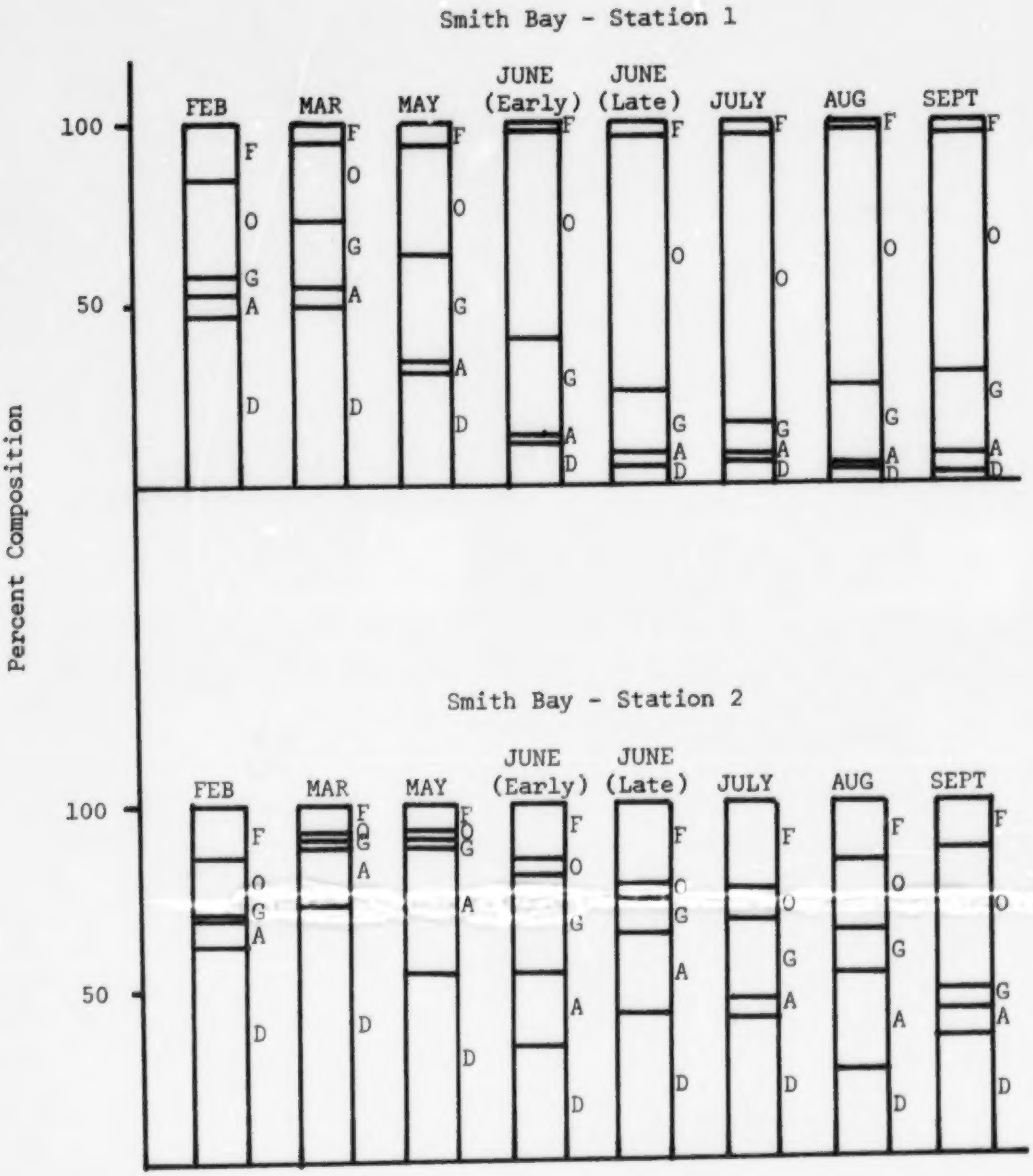

Figure 30 - Comparison, by percent composition, of the dominant orders of macro-benthic fauna present in Smith Bay, February through September 1972. (KEY: D - Diptera, A - Amphipoda, G - Gastropoda, O - Oligochaeta, F - Other Fauna)

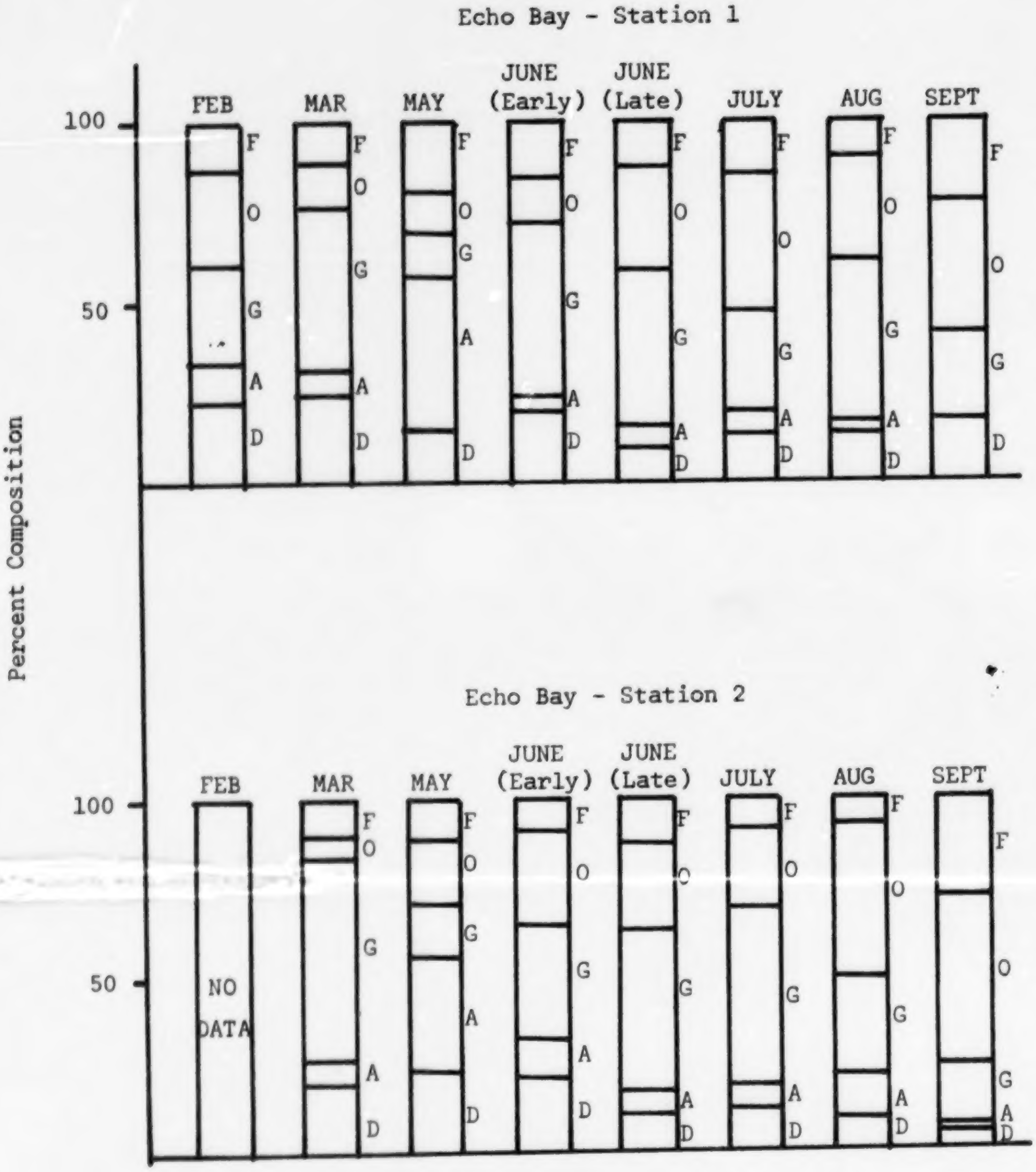

Figure 31 - Comparison, by percent composition, of the dominant orders of macro-benthic fauna present in Echo Bay, February through September 1972. (KEY: D - Diptera, A - Amphipoda, G - Gastropoda, O - Oligochaeta, F - Other Fauna)

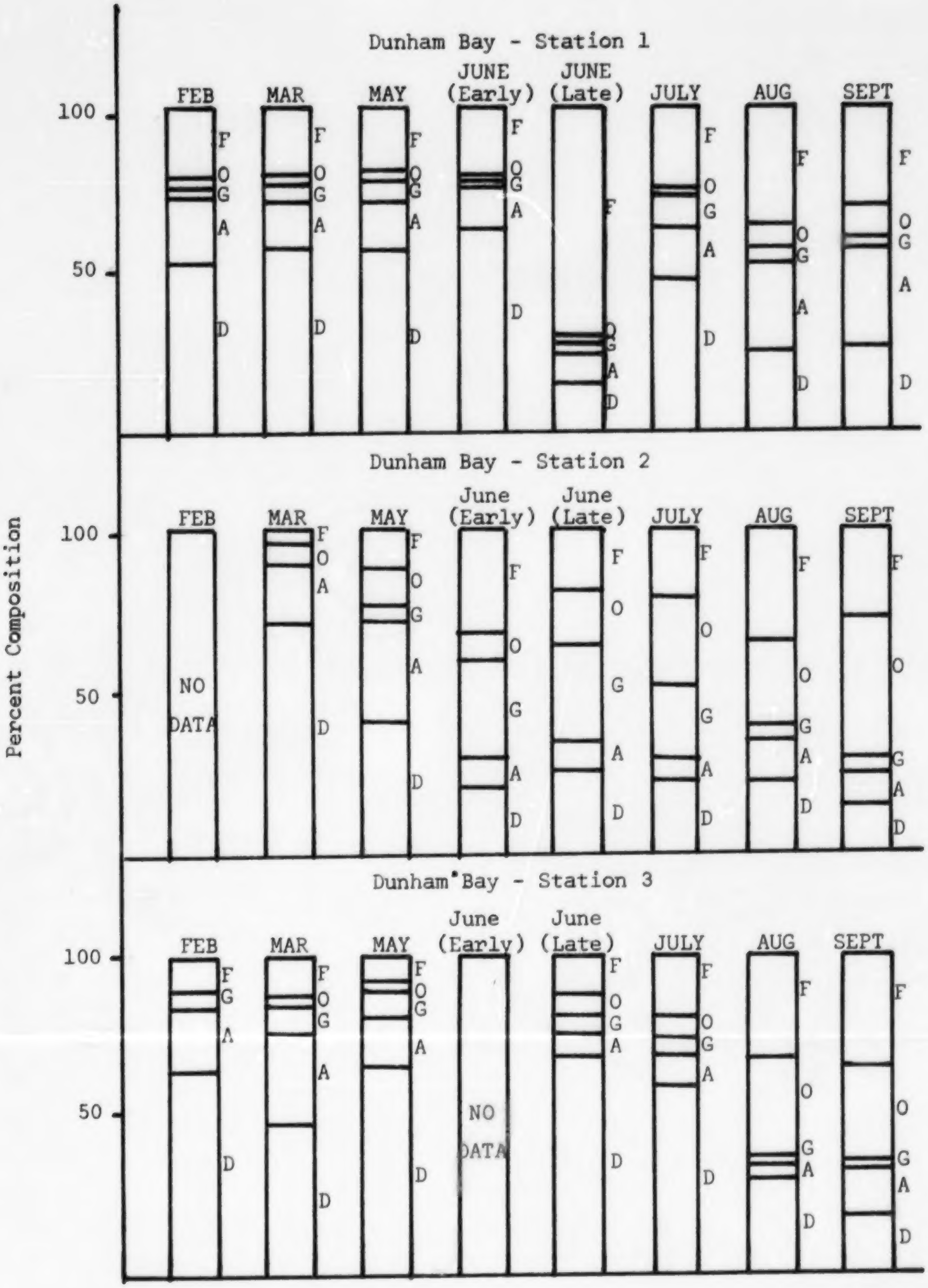

Figure 32 - Comparison, by percent composition, of the dominant orders of macro-benthic fauna present in Dunham Bay, February through September 1972. (KEY: D - Diptera, A - Amphipoda, G - Gastropoda, O - Oligochaeta, F - Other Fauna)

most diverse dipteran fauna. In contrast, the shallow stations appeared to support higher numbers of the oligochaetes and gastropods. Figures 33-46 illustrate the four dominant dipteran genera at each station.

It is important to note that high numbers of organisms may not be indicative of a healthy body of water if only a few species are present. A healthy or unstressed body of water should have numerous species represented and more moderate population densities. A study of Fig. 29 shows that Dunham Bay No. 2 and No. 3 and Smith Bay Station No. 2 averaged the most taxa found in each sample. Also, this is reflected in Table 40 which shows the total number of species found at each station.

Figure 29 shows the number of organisms per square meter of benthic area, during the period February through July 1972, in Smith, Dunham and Echo Bays. The organisms chosen were: *Polypedilium* and *Procladius*, dipterans; *Hyalella*, an amphipod; *Caenis*, an ephemeroptera; and *Amnicola*, a prosobranch snail. These genera were chosen because they were common to all of the stations and in higher numbers than other populations.

Diversity Index Values

In order to obtain an easily understood numerical comparison of the populations at each station, a diversity index ($\bar{d}$) was applied to the data. Table 49 lists the values obtained. Values ranged from a low of 1.42 at Smith Bay Station No. 1 in late June, to a high of 4.15 at Dunham Bay Station No. 3 in July. Diversity values fluctuated somewhat, especially in the warmer period from June through August. These data are discussed more extensively in a later portion of this section.

Generally, the values for each station are greater than 2.5 and values above 3.0 were found at all stations for some portion of the sampling period. The overall average $\bar{d}$ values for each station are given in Table 49. Note that only Smith No. 1 and Dunham No. 1 are less than 3.0, the theoretical value above which water might be considered unpolluted (Wilhm (93)). The average $\bar{d}$ values for the bays as a whole are Dunham Bay, 3.075; Echo Bay, 2.976; and Smith Bay, 2.786.

Generally, the diversity index values for deep and shallow stations within the same bay were not comparable. Maximum $\bar{d}$ values at deeper stations corresponded with depressed values at the shallow stations and vice versa. The highest $\bar{d}$ values for Smith No. 2 and Dunham No. 3 occurred from June through September. Maximum values for Smith No. 1 and Dunham No. 1 occurred prior to June and after July.

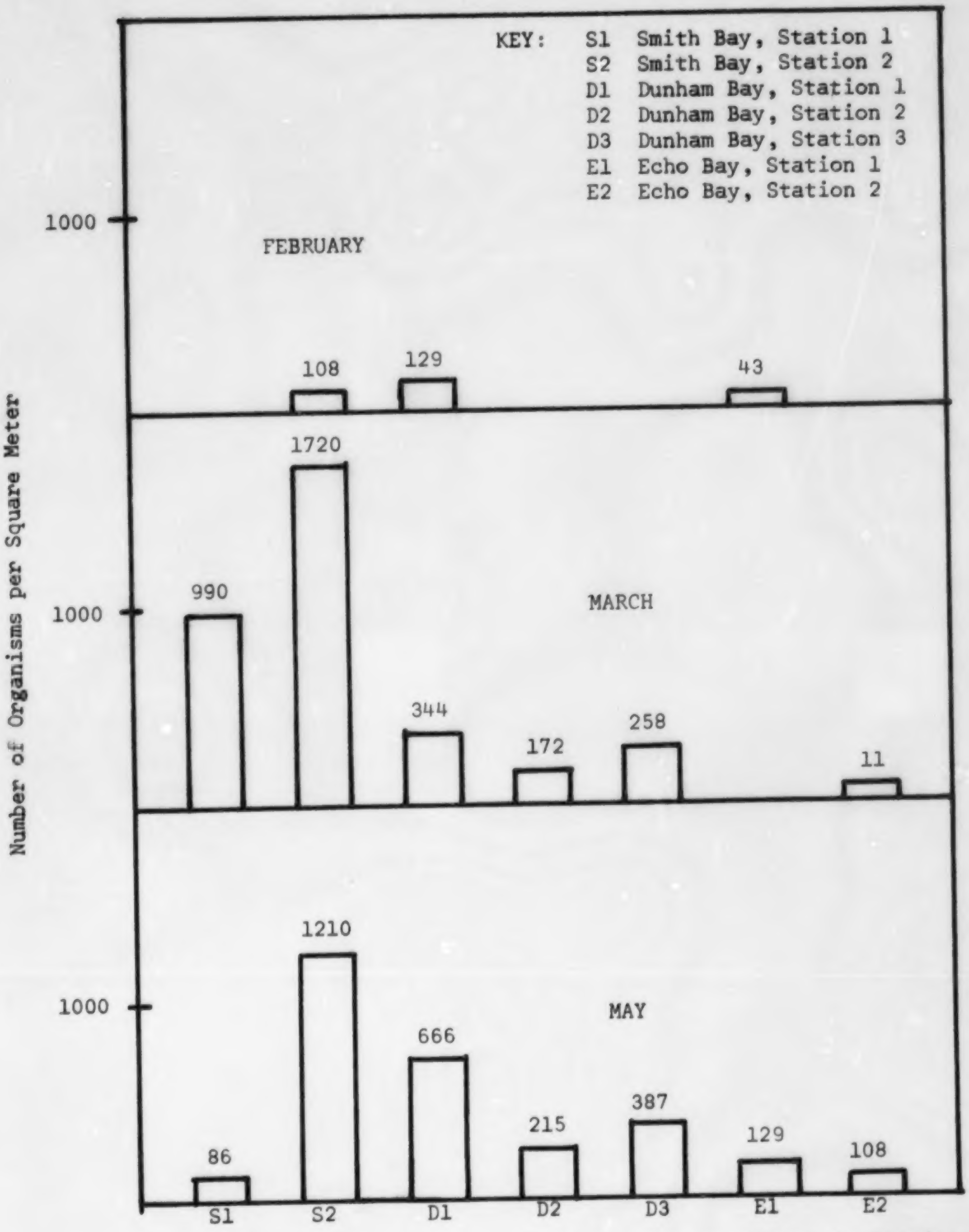

Figure 33 - Comparison of Populations of Polypedilium by Station in Three Bays of Lake George from February through May 1972

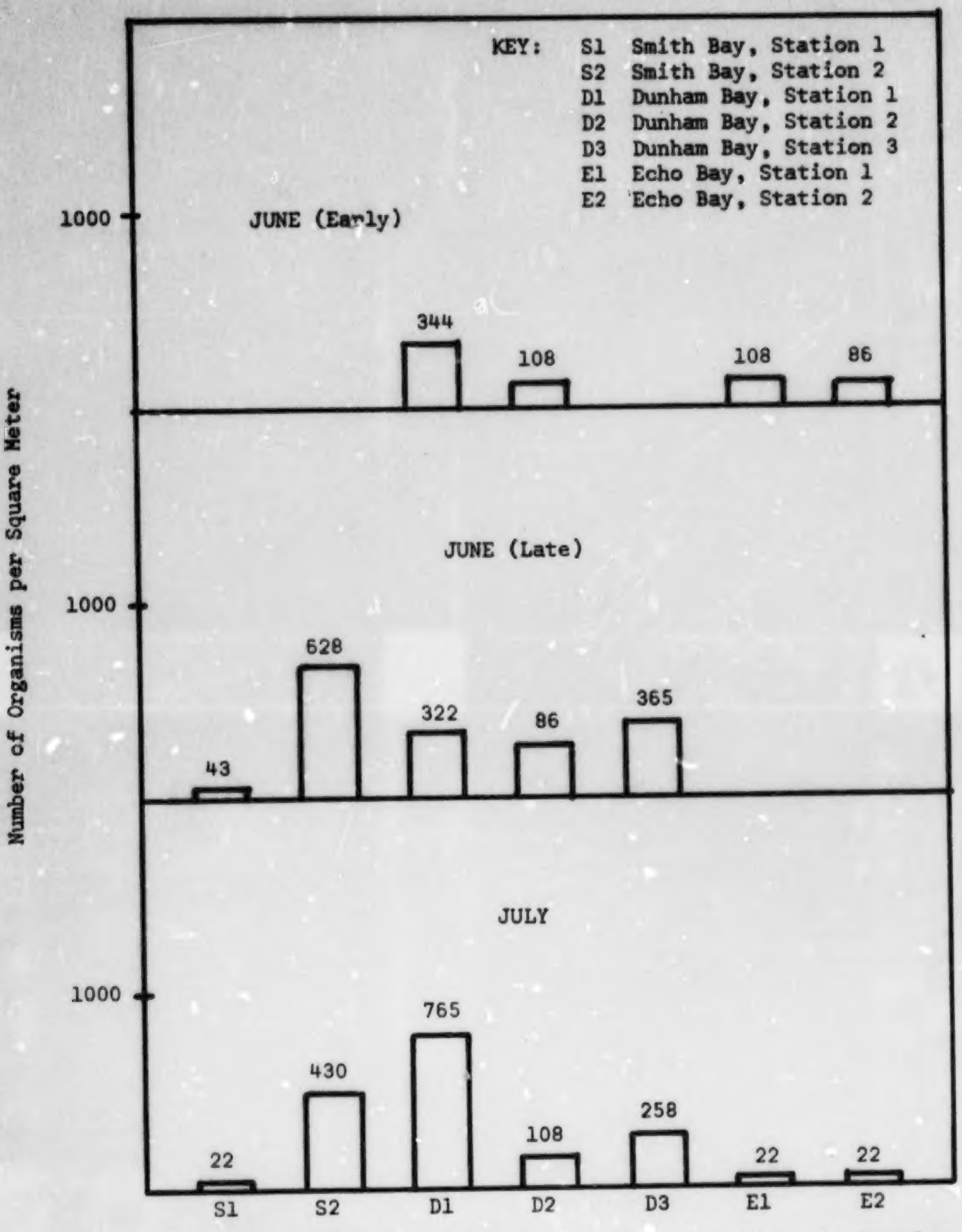

Figure 34 - Comparison of Populations of Polypedilium by Station in Three Bays of Lake George from June (early) through July 1972

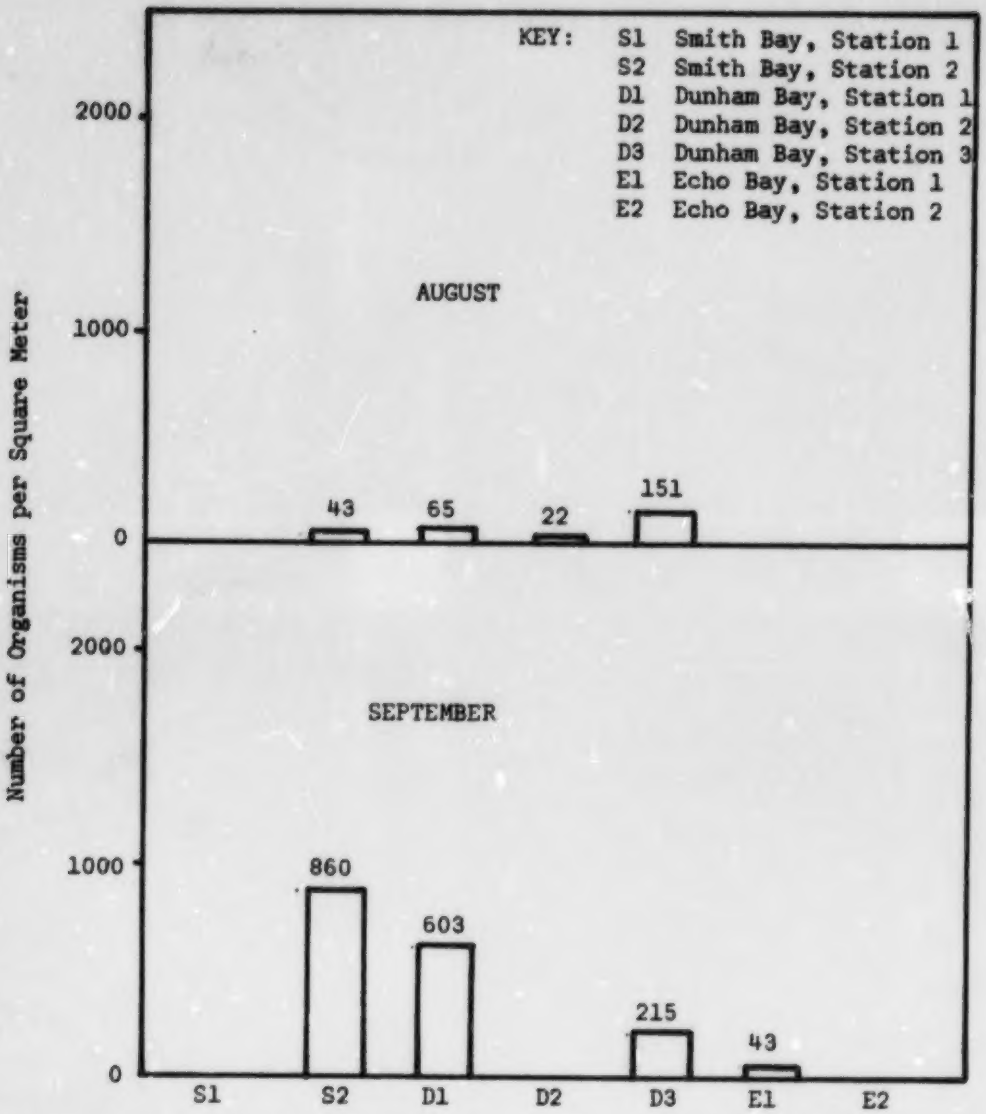

Figure 35 - Comparison of Populations of Polypedilium by Station in Three Bays of Lake George from August through September 1972

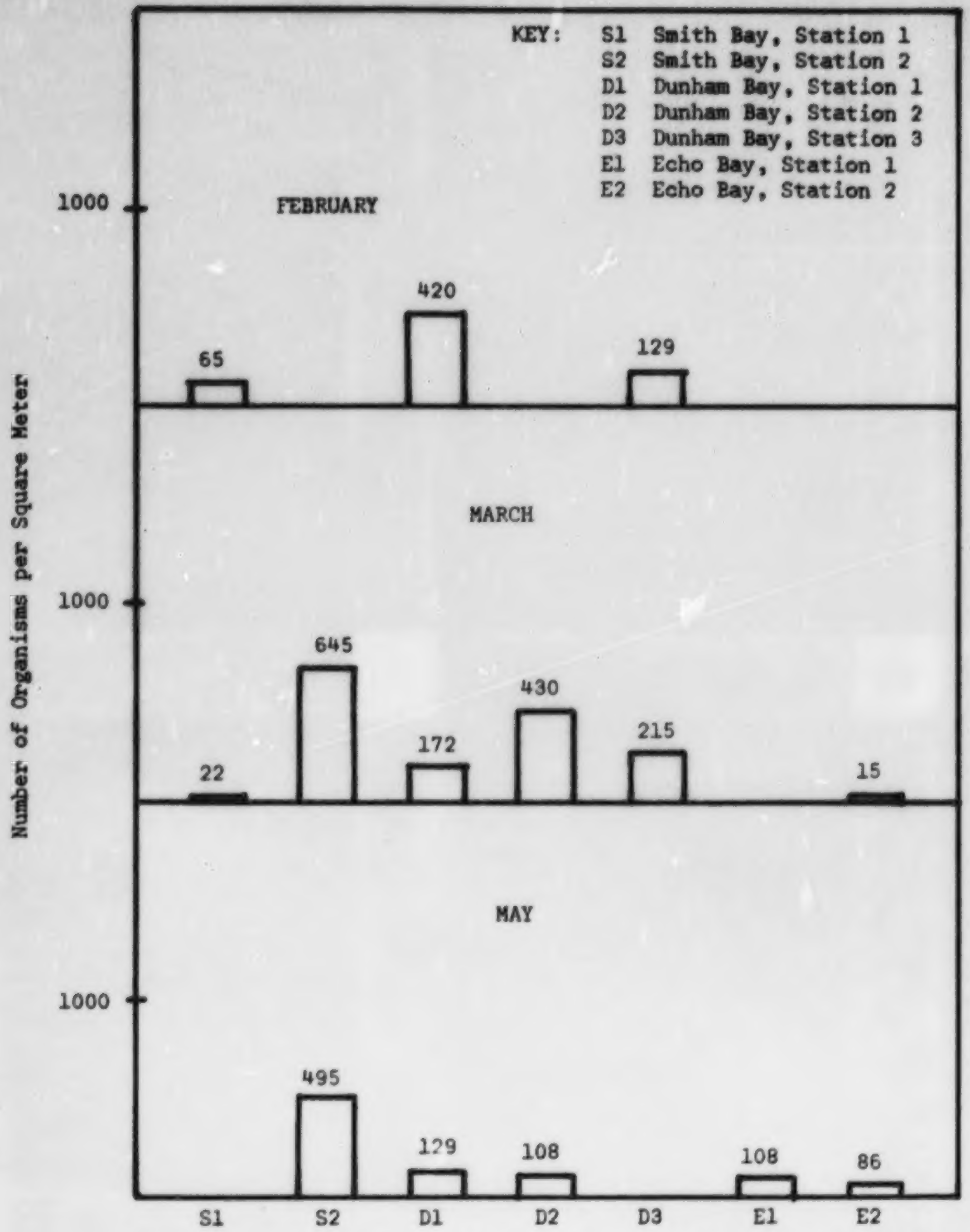

Figure 36 - Comparison of Populations of Procladius by Station in Three Bays of Lake George from February through May 1972

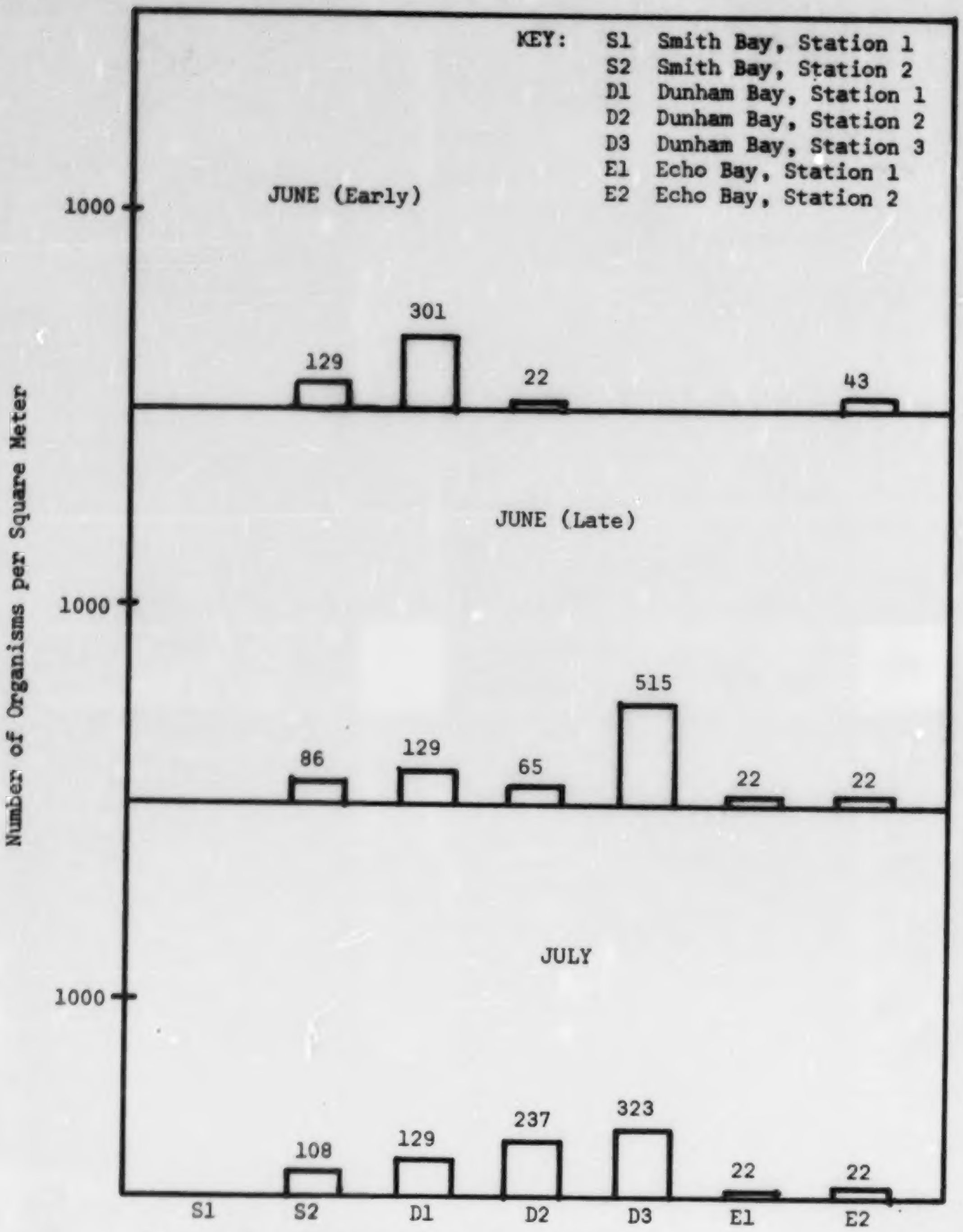

Figure 37 - Comparison of Populations of Procladius by Station in Three Bays of Lake George from June (early) through July 1972

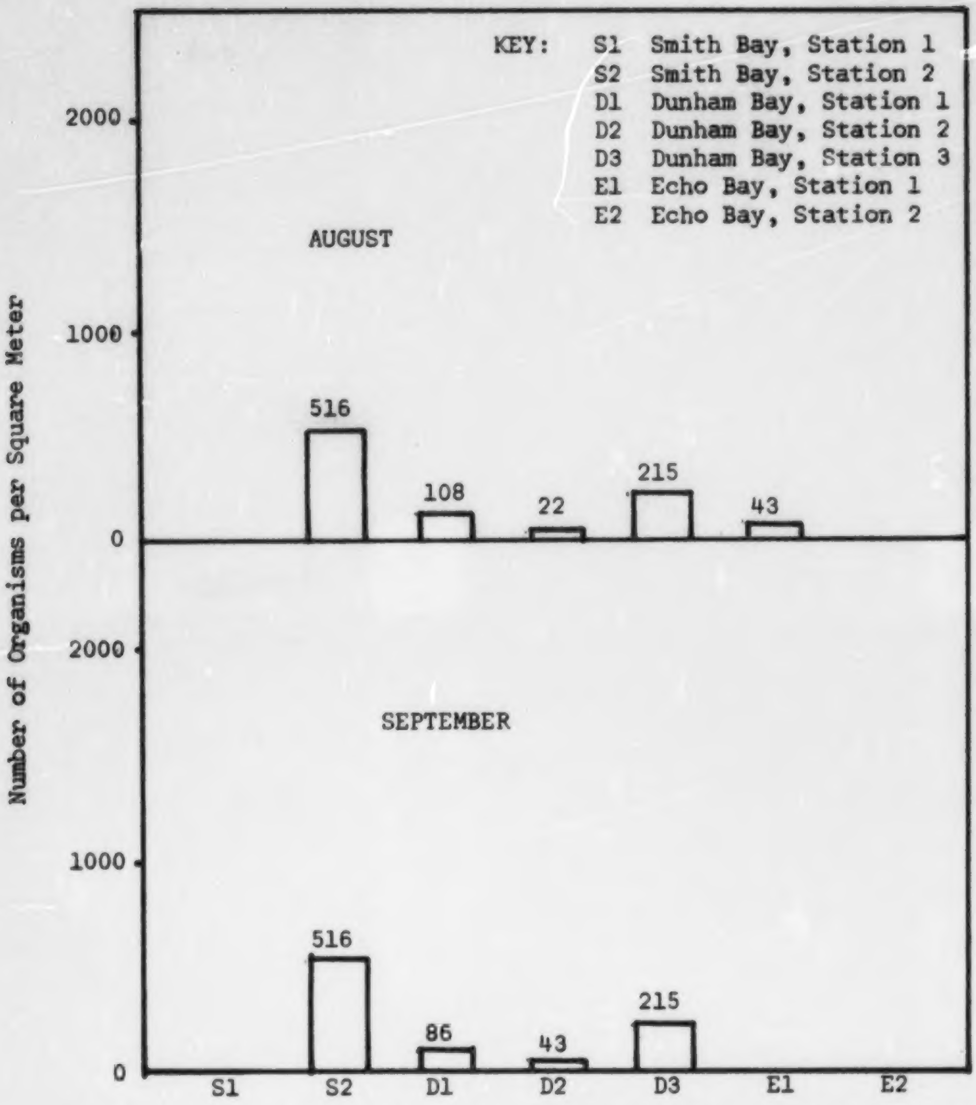

Figure 38 - Comparison of Populations of Procladius by Station in Three Bays of Lake George from August through September 1972

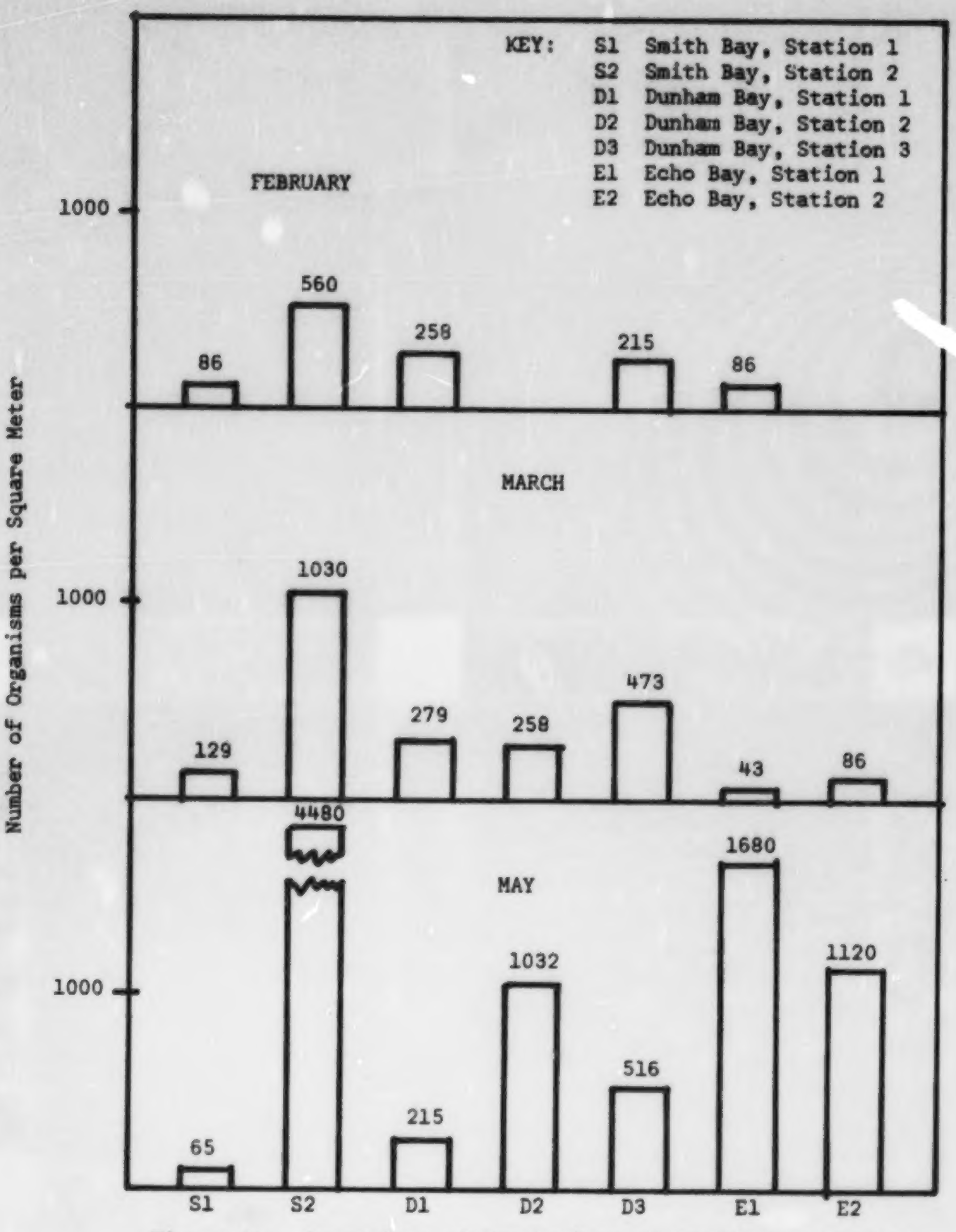

Figure 39 - Comparison of Populations of Hyalella by Station in Three Bays of Lake George from February through May 1972

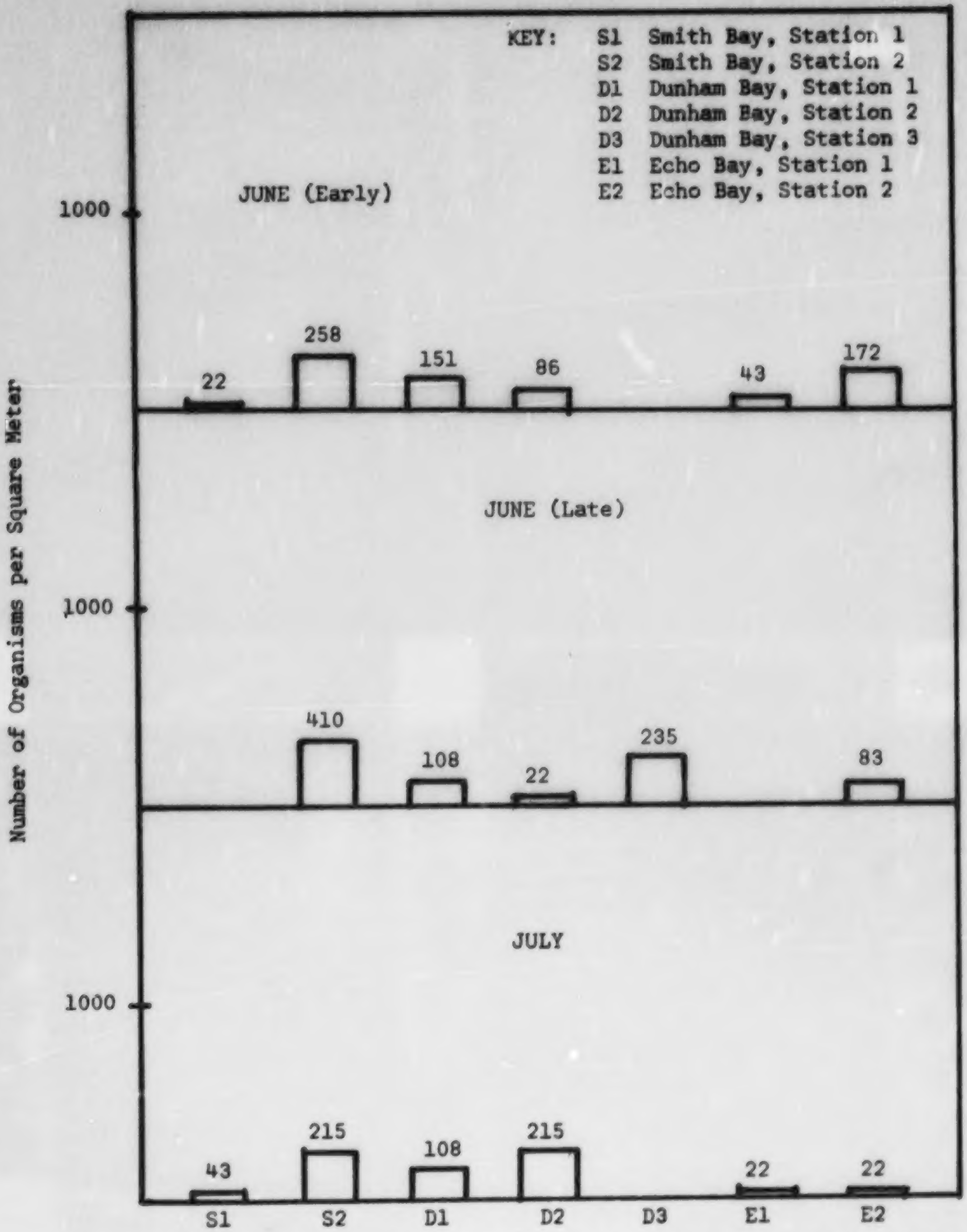

Figure 40 - Comparison of Populations of Hyalella by Station in Three Bays of Lake George from June (early) through July 1972

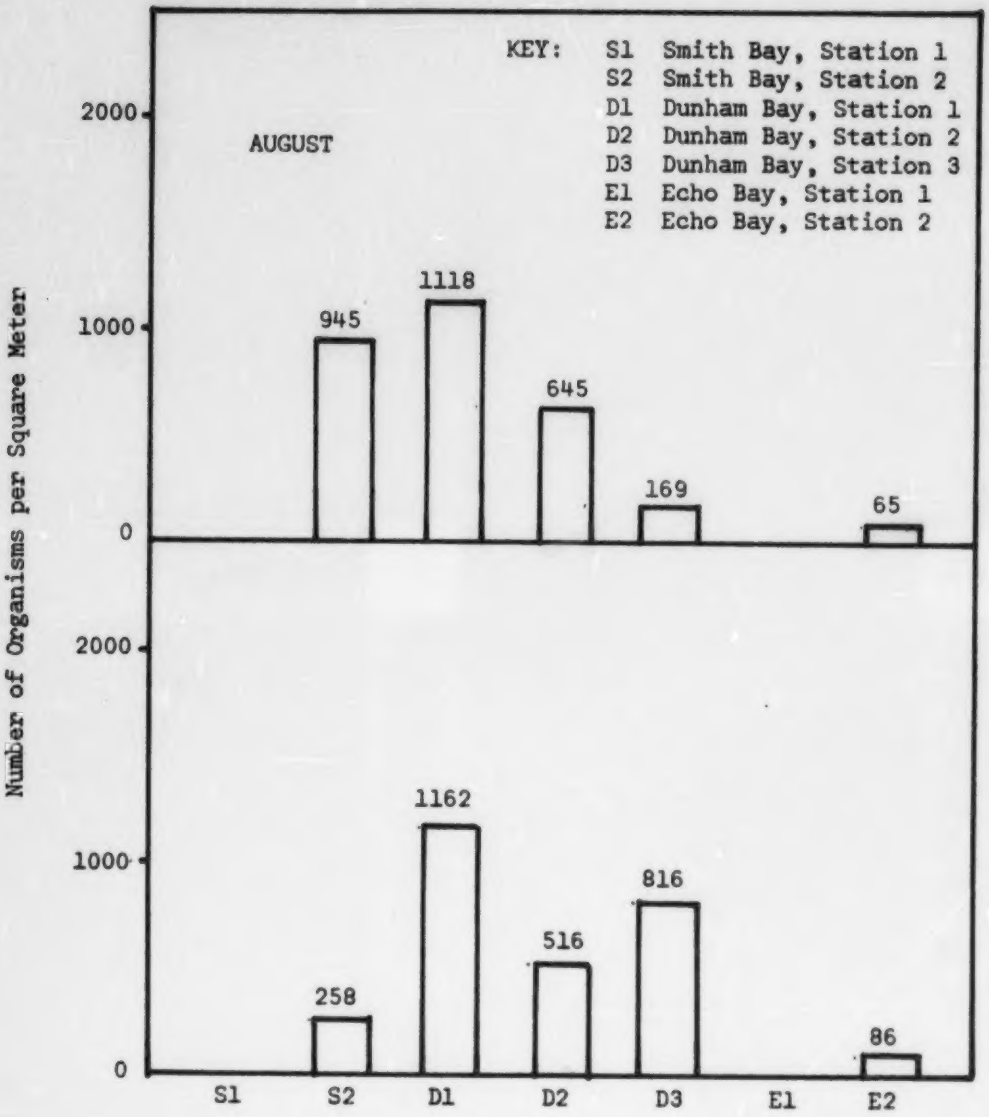

Figure 41 - Comparison of Populations of *Hyalella* by Station in Three Bays of Lake George from August through September 1972

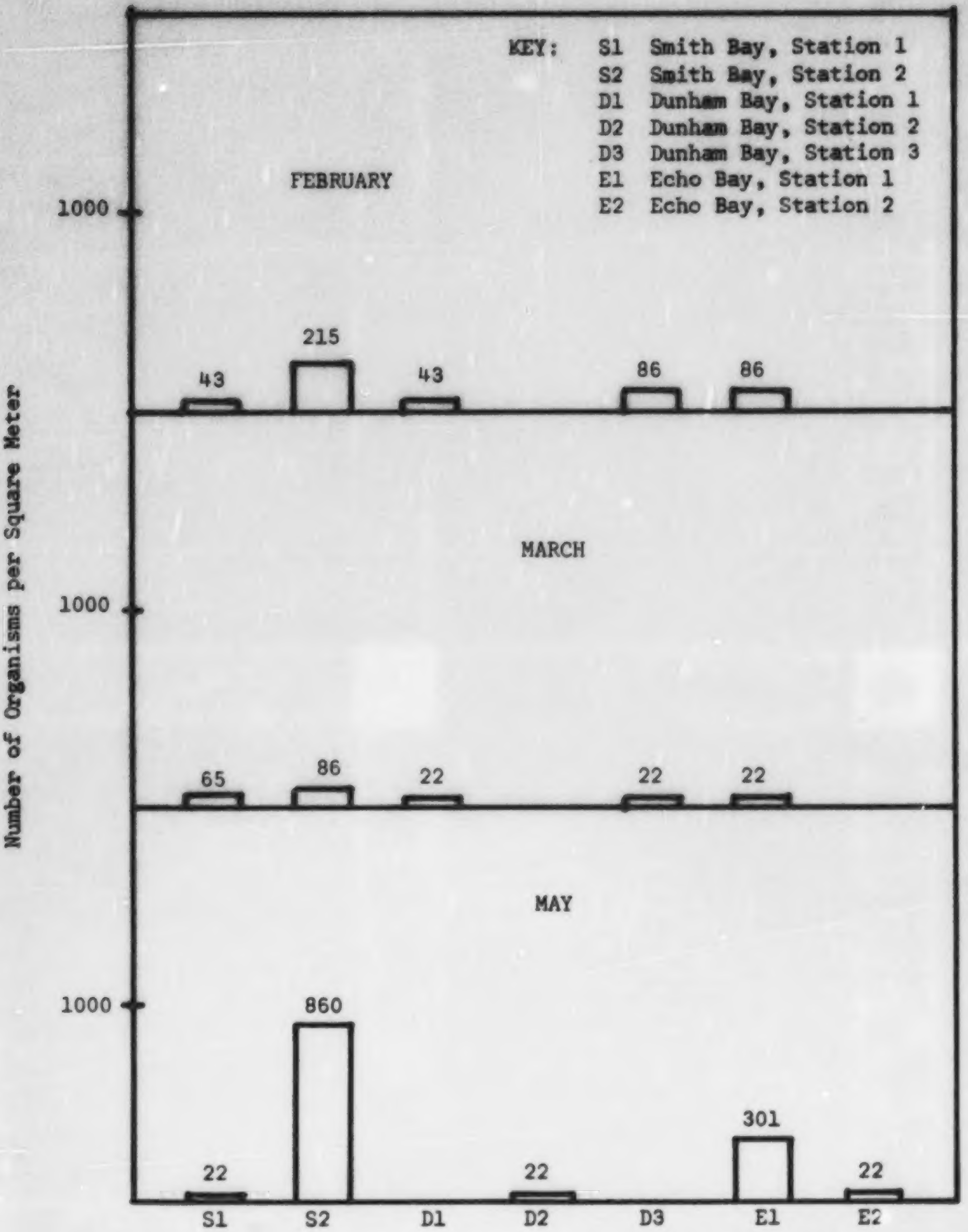

Figure 42 - Comparison of Populations of Caenis by Station in Three Bays of Lake George from February through May 1972

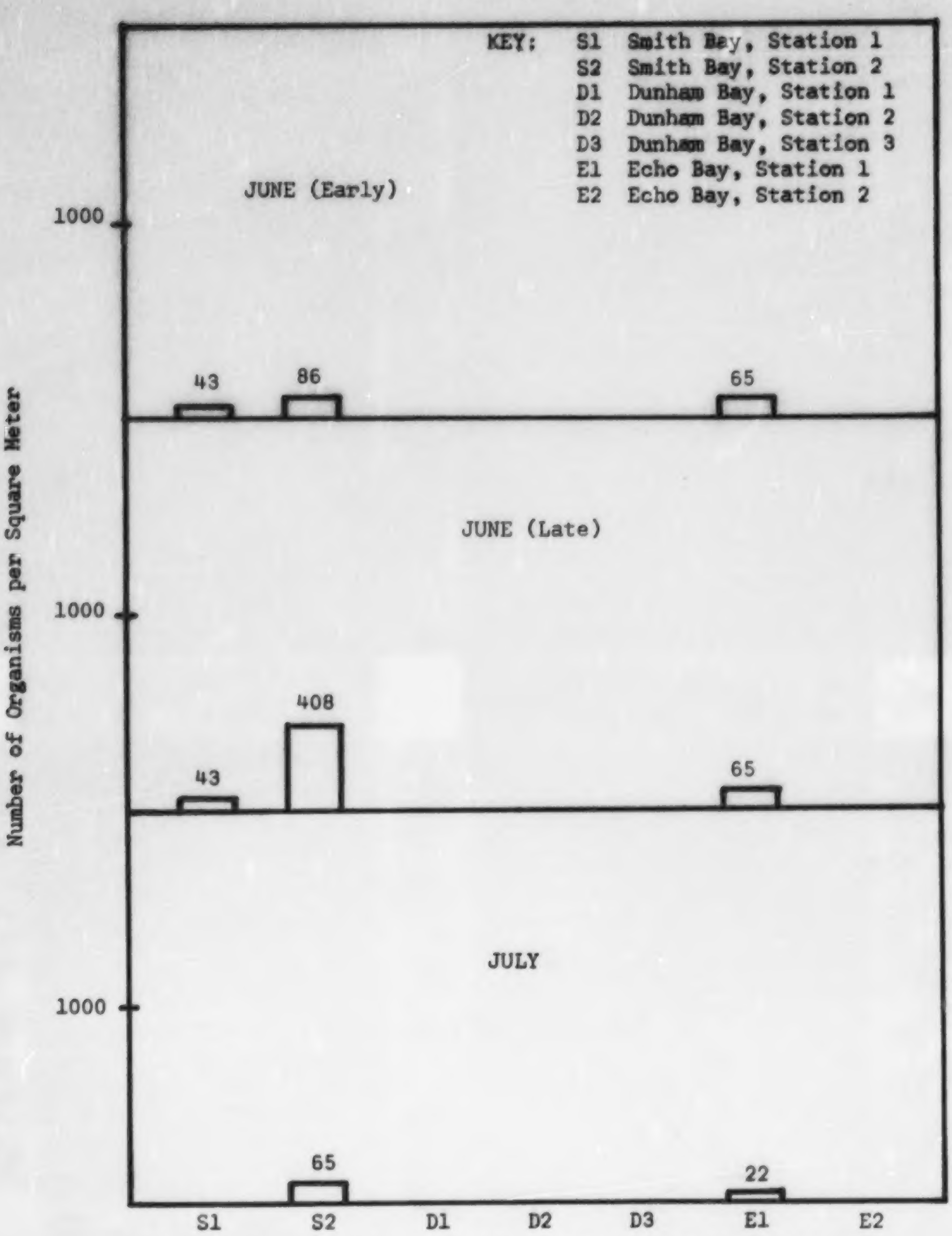

Figure 43 - Comparison of Populations of Caenis by Station in Three Bays of Lake George from June (early) through July 1972

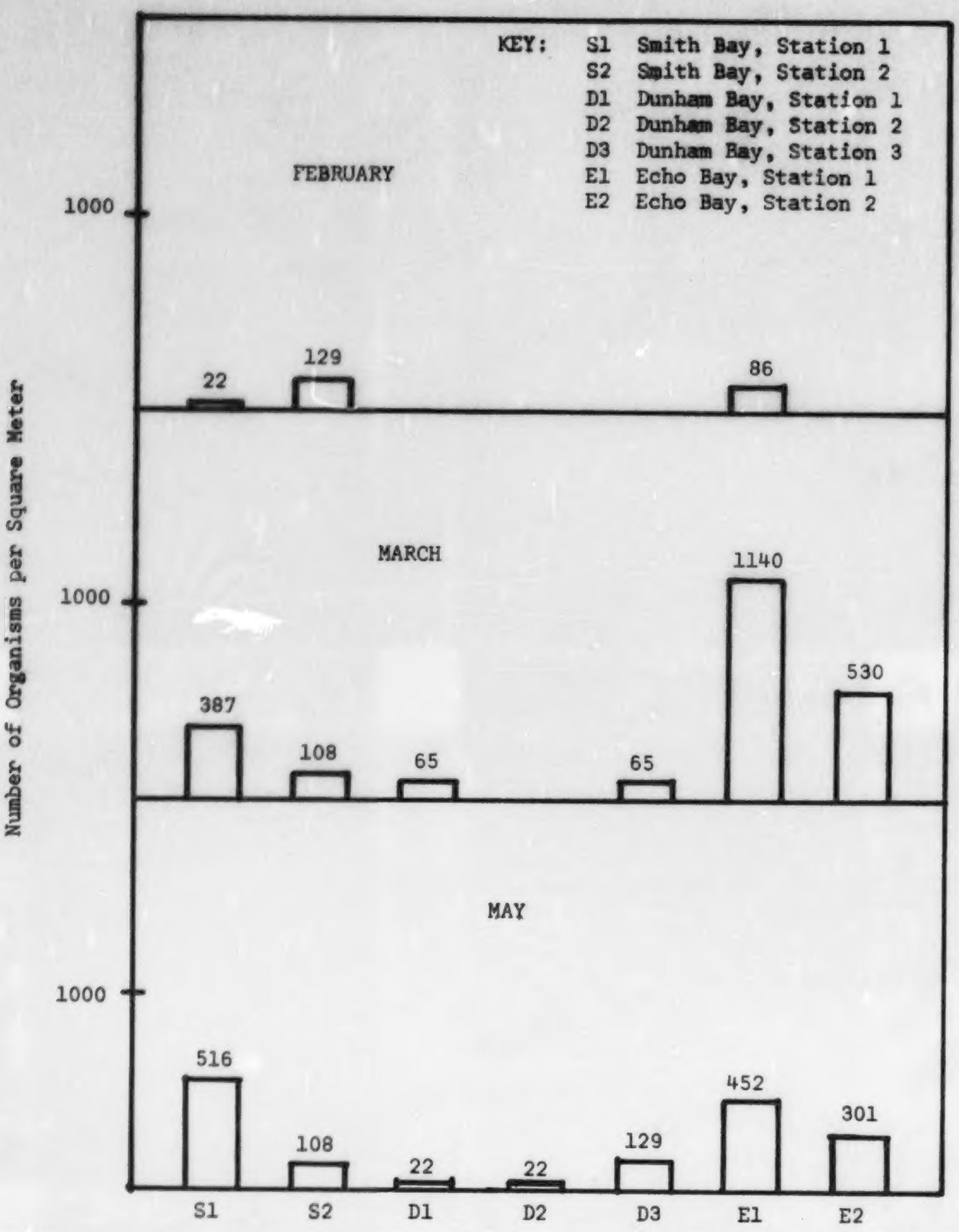

Figure 44 - Comparison of Populations of Amnicola by Station in Three Bays of Lake George from February through May 1972

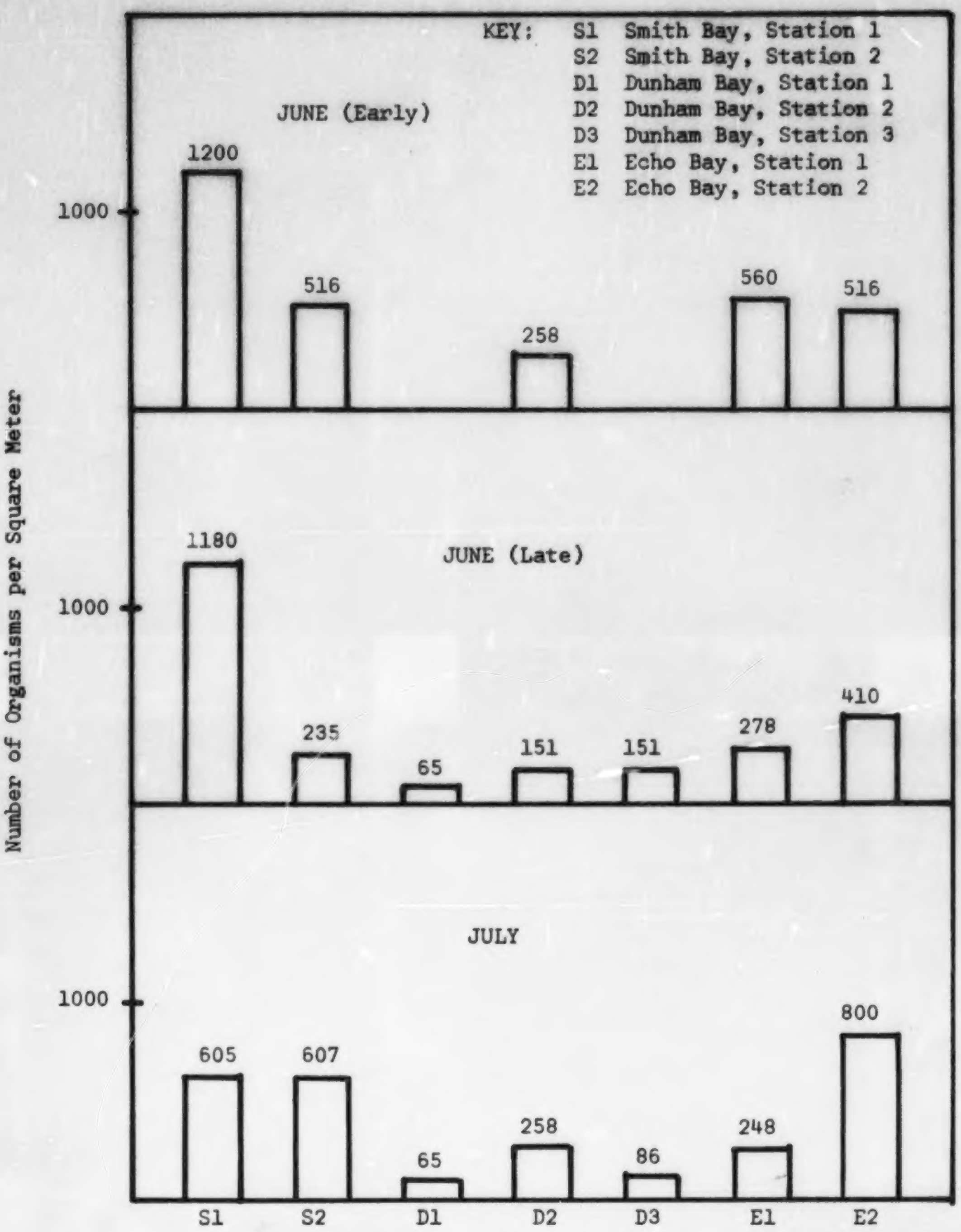

Figure 45 - Comparison of Populations of Amnicola by Station in Three Bays of Lake George from June (early) through July 1972

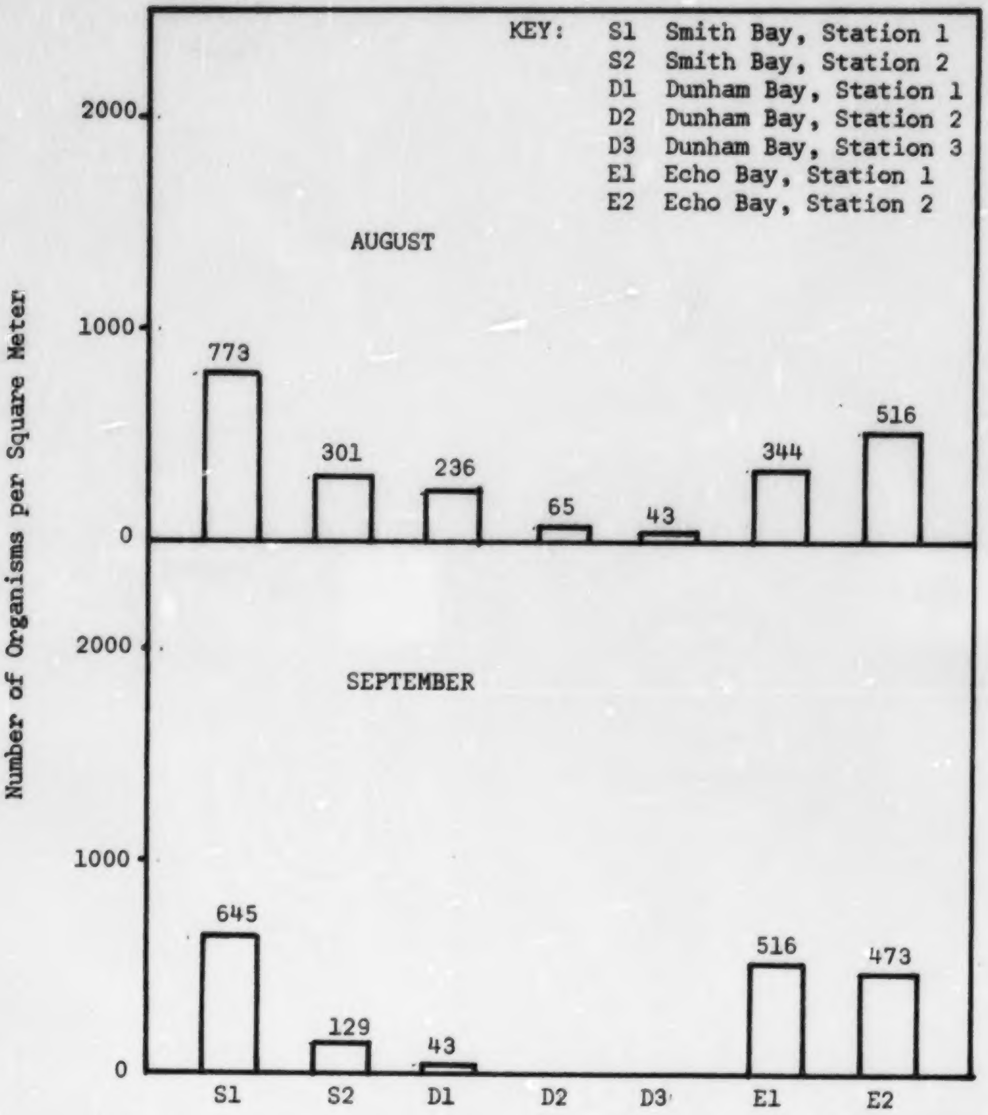

Figure 46 - Comparison of Populations of Amnicola by Station in Three Bays of Lake George from August through September 1972

Table 49

Diversity Index ($\bar{d}$) Values

1972 Sample Month	Stations						
	Smith 1	Smith 2	Dunham 1	Dunham 2	Dunham 3	Echo 1	Echo 2
February	3.022	3.079	3.219	--	2.281	2.880	--
	2.066	--	--	--	--	--	--
March	3.206	3.170	2.566	2.974	2.868	2.741	3.222
	2.934	2.651	3.058	--	2.638	2.877	2.645
	--	--	--	--	--	--	2.949
May	3.188	2.664	2.327	3.605	3.734	3.457	2.943
	3.079	2.858	2.858	2.724	2.549	2.428	2.925
June	2.020	3.442	2.422	3.380	--	2.875	3.080
(early)	2.191	--	2.920	3.323	--	3.043	2.792
June	1.422	3.405	1.626	3.291	3.373	3.081	2.639
(late)	1.640	3.228	1.982	3.142	3.654	2.578	2.783
July	1.505	3.578	2.998	3.606	3.727	3.597	2.533
	1.689	3.334	3.266	2.637	4.152	2.942	1.545
August	2.074	4.002	3.302	3.545	2.878	2.547	3.271
	2.874	3.475	3.223	3.351	--	3.606	2.850
September	2.432	3.881	3.539	3.796	3.392	3.396	3.775
Sta. Ave.	2.358	3.284	2.804	3.278	3.200	3.021	2.923
Bay Ave.	2.786		3.075			2.976	

Acute Static Bioassays

Test solutions containing exhaust products were prepared as outlined previously. Three test runs were made during August to supply test solutions for static bioassays. The resulting CCl_4 extractable hydrocarbon concentrations were 33.6 mg/l, 30.0 mg/l and 34.0 mg/l as calculated utilizing infrared spectrophotometry and standards of known hydrocarbon weights.

The test solutions were diluted as indicated in Tables 50(a)-50(q). Survival was plotted against concentrations as suggested by Warren (91) and others. TL_{50} data are shown in Figs. 47-50.

The 24 hr TL_{50} for Gammarus fasciatus and Amnicola limnosa was 1.16 mg/l and 1.08 mg/l, respectively. The 48 hr TL_{50} was slightly lower, 1.0 mg/l and 0.96 mg/l. In each case, acute toxicity (TL_{100}) was estimated at less than 10 mg/l. Temperatures ranging from 21° to 24.5° varied less than 1.0°C for any given trial during the test period. D.O. never fell below 6.0 nor varied more than 2.5 mg/l. Alkalinity and pH of the standard fresh water was comparable to those in the bays studied. The survival rate in the control bottles was not always 100%; however, a survival rate of at least 80% and usually 90 to 100% occurred in the control samples in all but one of the test results (see Table 50(i)).

Toxic levels appeared to be considerably lower than expected. In addition, the TL_{50}'s for both of the test organisms were very similar and occurred over a narrow range. For each organism and test period the bioassay was repeated at least three times.

DISCUSSION

Field Studies

It is probable that the characteristic differences (other than size) of the three bays examined played a role in the variation of composition and abundance of the benthic communities among the bays and between individual stations within the same bay. Reid (61), Odum (52) and others state that benthic fauna are not evenly distributed throughout a given lake. In addition, there are often noticeable differences between the fauna of different lakes. As noted, the shallow station in Smith Bay (Station No. 1) was principally sand in composition, which may have been of significance in the low $\bar{d}$ values computed for that station since the composition of bottom sediments has been considered of prime importance in affecting the development of these communities (Moon (48)), Eggleton (20), Kendeigh (37)). Sand Bottoms are unstable and abrasive and may be limiting; mud bottoms are a great deal more productive. The dominant life form at Station No. 1 throughout most of the sampling period was the Oligochaete, Tubifex (25-75% of the total population). Dunham Bay stations (primarily silt and organic detritus) appeared

Table 50(a)

Bioassay Data

Organism Tested: Gammarus fasciatus Date: 8-8-72
Test Duration: 24 hr Original Conc. of Solution: 33.6 (mg/1)
Run No.: 1 No. Test Organisms Used: 10

Test Conc. (mg/1)	Initial Temp. (°C)	Initial D. O. (mg/1)	Final Temp. (°C)	Final D. O. (mg/1)	No. Organisms Surviving
0.000	22.0	9.2	22.5	8.6	10
0.067	21.5	9.4	22.0	8.4	10
0.672	22.0	8.8	22.0	8.6	10
3.360	22.0	9.0	21.5	8.6	0
8.400	22.5	9.2	22.0	8.8	0
16.800	23.0	9.2	22.0	8.4	0
33.600	22.5	9.4	22.5	8.8	0

Table 50(b)

Bioassay Data

Organism Tested: Gammarus fasciatus Date: 8-10-72
Test Duration: 24 hr Original Conc. of Solution: 33.6 (mg/1)
Run No.: 2 No. Test Organisms Used: 10

Test Conc. (mg/1)	Initial Temp. (°C)	Initial D. O. (mg/1)	Final Temp. (°C)	Final D. O. (mg/1)	No. Organisms Surviving
0.000	21.0	8.6	22.0	8.4	10
0.672	21.0	8.8	22.5	8.2	9
1.344	21.0	8.8	22.0	8.0	1
2.016	21.0	9.0	22.0	8.5	0
2.688	21.0	8.6	22.0	8.0	0
3.360	21.5	9.0	22.0	8.6	0

Table 50(c)

Bioassay Data

Organism Tested: Gammarus fasciatus Date: 8-15-72
Test Duration: 24 hr Original Conc. of Solution: 33.6 (mg/l)
Run No. 3 No. Test Organisms Used: 10

Test Conc. (mg/l)	Initial Temp. (°C)	Initial D. O. (mg/l)	Final Temp. (°C)	Final D. O. (mg/l)	No. Organisms Surviving
0.000	22.0	9.4	21.5	8.6	10
0.941	22.0	9.2	21.5	8.7	7
1.076	22.0	9.2	22.0	8.4	9
1.210	22.0	9.2	21.5	8.6	5
1.345	22.0	9.4	21.5	8.8	6
1.470	22.5	9.0	21.5	8.4	1

Table 50(d)

Bioassay Data

Organism Tested: Gammarus fasciatus Date: 8-22-72
Test Duration: 24 hr Original Conc. of Solution: 30.0 (mg/l)
Run No.: 4 No. Test Organisms Used: 10

Test Conc. (mg/l)	Initial Temp. (°C)	Initial D. O. (mg/l)	Final Temp. (°C)	Final D. O. (mg/l)	No. Organisms Surviving
0.000	24.0	7.9	24.5	7.5	8
0.720	24.0	8.4	24.5	7.8	10
0.840	24.0	8.1	24.5	7.7	7
0.961	24.0	8.2	24.5	7.8	9
1.080	24.0	8.4	24.5	7.8	6
1.210	24.0	8.2	24.5	7.7	4

Table 50(e)

Bioassay Data

Organism Tested: Gammarus fasciatus Date: 8-28-72
Test Duration: 24 hr Original Conc. of Solution: 30.0 (mg/l)
Run No.: 5 No. Test Organisms Used: 10

Test Conc. (mg/l)	Initial Temp. (°C)	Initial D. O. (mg/l)	Final Temp. (°C)	Final D. O. (mg/l)	No. Organisms Surviving
0.000	23.0	8.3	22.5	7.6	9
0.840	23.5	8.1	22.5	7.8	9
0.961	23.0	8.2	22.5	7.4	8
1.080	23.0	8.4	22.0	7.9	7
1.200	23.5	8.2	22.0	7.4	6
1.316	23.0	8.4	22.0	7.6	4

Table 50(f)

Bioassay Data

Organism Tested: Gammarus fasciatus Date: 8-31-72
Test Duration: 24 hr Original Conc. of Solution: 30.0 (mg/l)
Run No.: 6 No. Test Organisms Used: 10

Test Conc. (mg/l)	Initial Temp. (°C)	Initial D. O. (mg/l)	Final Temp. (°C)	Final D. O. (mg/l)	No. Organisms Surviving
0.00	22.5	8.8	22.5	8.0	8
0.96	22.0	8.6	22.0	7.8	6
1.20	22.5	8.6	22.0	7.6	7
1.44	22.0	8.7	22.0	7.8	7
1.68	22.0	8.6	22.5	7.9	5
1.92	22.5	8.7	22.0	7.8	6

Table 50(g)

Bioassay Data

Organism Tested: Gammarus fasciatus Date: 9-5-72
Test Duration: 24 hr Original Conc. of Solution: 34.0 (mg/l)
Run No.: 7 No. Test Organisms Used: 10

Test Conc. (mg/l)	Initial Temp. (°C)	Initial D. O. (mg/l)	Final Temp. (°C)	Final D. O. (mg/l)	No. Organisms Surviving
0.000	23.0	8.4	22.0	7.4	9
0.702	23.0	8.3	22.0	7.2	7
0.809	23.0	8.4	22.0	7.3	6
0.916	23.0	8.4	22.0	7.5	7
1.025	23.0	8.2	22.0	7.3	6
1.135	23.0	8.4	22.0	7.3	5
1.240	23.0	8.3	22.0	7.4	3

Table 50(h)

Bioassay Data

Organism Tested: Gammarus fasciatus Date: 8-15-72
Test Duration: 48 hr Original Conc. of Solution: 33.6 (mg/l)
Run No.: 1 No. Test Organisms Used: 10

Test Conc. (mg/l)	Initial Temp. (°C)	Initial D. O. (mg/l)	Final Temp. (°C)	Final D. O. (mg/l)	No. Organisms Surviving
0.000	22.0	9.4	22.0	8.0	10
0.941	22.0	9.2	22.0	8.2	7
1.076	22.0	9.2	22.0	7.8	5
1.210	22.0	9.2	22.0	7.6	4
1.345	22.0	9.4	22.0	8.0	5
1.470	22.0	9.0	22.0	7.8	2

Table 50(i)

Bioassay Data

Organism Tested: Gammarus fasciatus Date: 8-22-72
Test Duration: 48 hr Original Conc. of Solution: 30.0 (mg/l)
Run No.: 2 No. Test Organisms Used: 10

Test Conc. (mg/l)	Initial Temp. (°C)	Initial D. O. (mg/l)	Final Temp. (°C)	Final D. O. (mg/l)	No. Organisms Surviving
0.000	24.0	7.9	22.0	7.0	7
0.720	24.0	8.4	22.0	7.2	9
0.840	24.0	8.1	22.0	6.8	4
0.961	24.0	8.2	22.0	7.2	6
1.080	24.0	8.4	22.0	7.2	3
1.210	24.0	8.2	22.0	7.6	1

Table 50(j)

Bioassay Data

Organism Tested: Gammarus fasciatus Date: 8-28-72
Test Duration: 48 hr Original Conc. of Solution: 30.0 (mg/l)
Run No.: 3 No. Test Organisms Used: 10

Test Conc. (mg/l)	Initial Temp. (°C)	Initial D. O. (mg/l)	Final Temp. (°C)	Final D. O. (mg/l)	No. Organisms Surviving
0.000	23.0	8.3	22.5	7.0	8
0.840	23.5	8.1	22.5	7.0	7
0.961	23.0	8.2	22.5	6.8	8
1.080	23.0	8.4	22.0	7.0	7
1.200	23.5	8.2	22.0	6.8	5
1.316	23.0	8.4	22.0	6.6	3

Table 50(k)

Bioassay Data

Organism Tested: Gammarus fasciatus Date: 9-5-72
Test Duration: 48 hr Original Conc. of Solution: 34.0 (mg/l)
Run No.: 4 No. Test Organisms Used: 10

Test Conc. (mg/l)	Initial Temp. (°C)	Initial D. O. (mg/l)	Final Temp. (°C)	Final D. O. (mg/l)	No. Organisms Surviving
0.000	22.0	8.8	22.0	6.8	8
0.702	22.0	8.6	22.0	7.0	4
0.809	22.0	8.6	22.0	6.8	5
0.916	22.0	8.7	22.0	6.6	6
1.025	22.0	8.6	22.0	7.0	6
1.135	22.0	8.7	22.0	6.9	4
1.240	22.5	8.6	22.0	6.8	2

Table 50(l)

Bioassay Data

Organism Tested: Amnicola limnosa Date: 8-22-72
Test Duration: 24 hrs Original Conc. of Solution: 33.6 (mg/l)
Run No.: 1 No. Test Organisms Used: 10

Test Conc. (mg/l)	Initial Temp. (°C)	Initial D. O. (mg/l)	Final Temp. (°C)	Final D. O. (mg/l)	No. Organisms Surviving
0.00	24.0	8.3	24.5	7.4	10
0.72	24.0	8.4	24.5	7.4	9
0.84	24.0	8.4	24.5	7.3	10
0.96	24.0	8.4	24.5	7.3	8
1.08	24.0	8.4	24.5	7.3	6
1.24	24.0	8.5	24.5	7.3	3

Table 50(m)

Bioassay Data

Organism Tested: Amnicola limnosa Date: 8-28-72
Test Duration: 24 hr Original Conc. of Solution: 30.0 (mg/l)
Run No.: 2 No. Test Organisms Used: 10

Test Conc. (mg/l)	Initial Temp. (°C)	Initial D. O. (mg/l)	Final Temp. (°C)	Final D. O. (mg/l)	No. Organisms Surviving
0.00	23.0	8.4	23.0	6.8	9
0.84	23.0	8.3	23.0	6.9	9
0.96	23.0	8.2	23.0	6.7	6
1.08	23.0	8.2	23.0	6.9	5
1.21	23.0	8.2	23.0	6.9	1
1.316	23.0	8.3	23.0	6.8	0

Table 50(n)

Bioassay Data

Organism Tested: Amnicola limnosa Date: 8-31-72
Test Duration: 24 hr Original Conc. of Solution: 30.0 (mg/l)
Run No.: 3 No. Test Organisms Used: 10

Test Conc. (mg/l)	Initial Temp. (°C)	Initial D. O. (mg/l)	Final Temp. (°C)	Final D. O. (mg/l)	No. Organisms Surviving
0.00	22.0	8.8	23.0	7.0	9
0.96	22.0	8.6	23.0	7.1	7
1.20	22.0	8.6	23.0	6.9	4
1.44	22.0	8.8	23.0	6.8	0
1.68	22.0	8.6	23.0	7.0	0
1.92	22.0	8.7	23.5	7.0	0

Table 50(o)

Bioassay Data

Organism Tested: Amnicola limnosa Date: 8-22-72
Test Duration: 48 hr Original Conc. of Solution: 33.6 (mg/l)
Run No.: 1 No. Test Organisms Used: 10

Test Conc. (mg/l)	Initial Temp. (°C)	Initial D. O. (mg/l)	Final Temp. (°C)	Final D. O. (mg/l)	No. Organisms Surviving
0.000	23.0	8.2	24.0	6.5	9
0.720	23.0	8.4	24.0	6.6	8
0.890	23.0	8.4	24.0	6.6	5
0.961	23.0	8.3	24.0	6.8	2
1.080	23.0	8.2	24.0	6.5	0
1.210	23.0	8.3	24.0	6.6	0

Table 50(p)

Bioassay Data

Organism Tested: Amnicola limnosa Date: 8-28-72
Test Duration: 48 hr Original Conc. of Solution: 30.0 (mg/l)
Run No.: 2 No. Test Organisms Used: 10

Test Conc. (mg/l)	Initial Temp. (°C)	Initial D. O. (mg/l)	Final Temp. (°C)	Final D. O. (mg/l)	No. Organisms Surviving
0.000	23.0	8.4	23.0	6.0	8
0.840	23.0	8.2	23.0	6.2	7
0.961	23.0	8.2	23.0	6.3	4
1.080	23.0	8.3	23.0	6.2	1
1.210	23.0	8.2	23.0	6.2	0
1.316	23.0	8.2	23.0	6.3	0

Table 50(q)

Bioassay Data

Organism Tested: Amnicola limnosa Date: 8-31-72
Test Duration: 48 hr Original Conc. of Solution: 30.0 (mg/l)
Run No.: 3 No. Test Organisms Used: 10

Test Conc. (mg/l)	Initial Temp. (°C)	Initial D. O. (mg/l)	Final Temp. (°C)	Final D. O. (mg/l)	No. Organisms Surviving
0.000	22.0	8.8	23.0	6.6	9
0.961	22.0	8.6	23.0	6.5	7
1.210	22.0	8.6	23.0	6.3	4
1.440	22.0	8.6	23.0	6.4	0
1.680	22.0	8.6	23.0	6.6	0
1.920	22.0	8.8	23.0	6.4	0

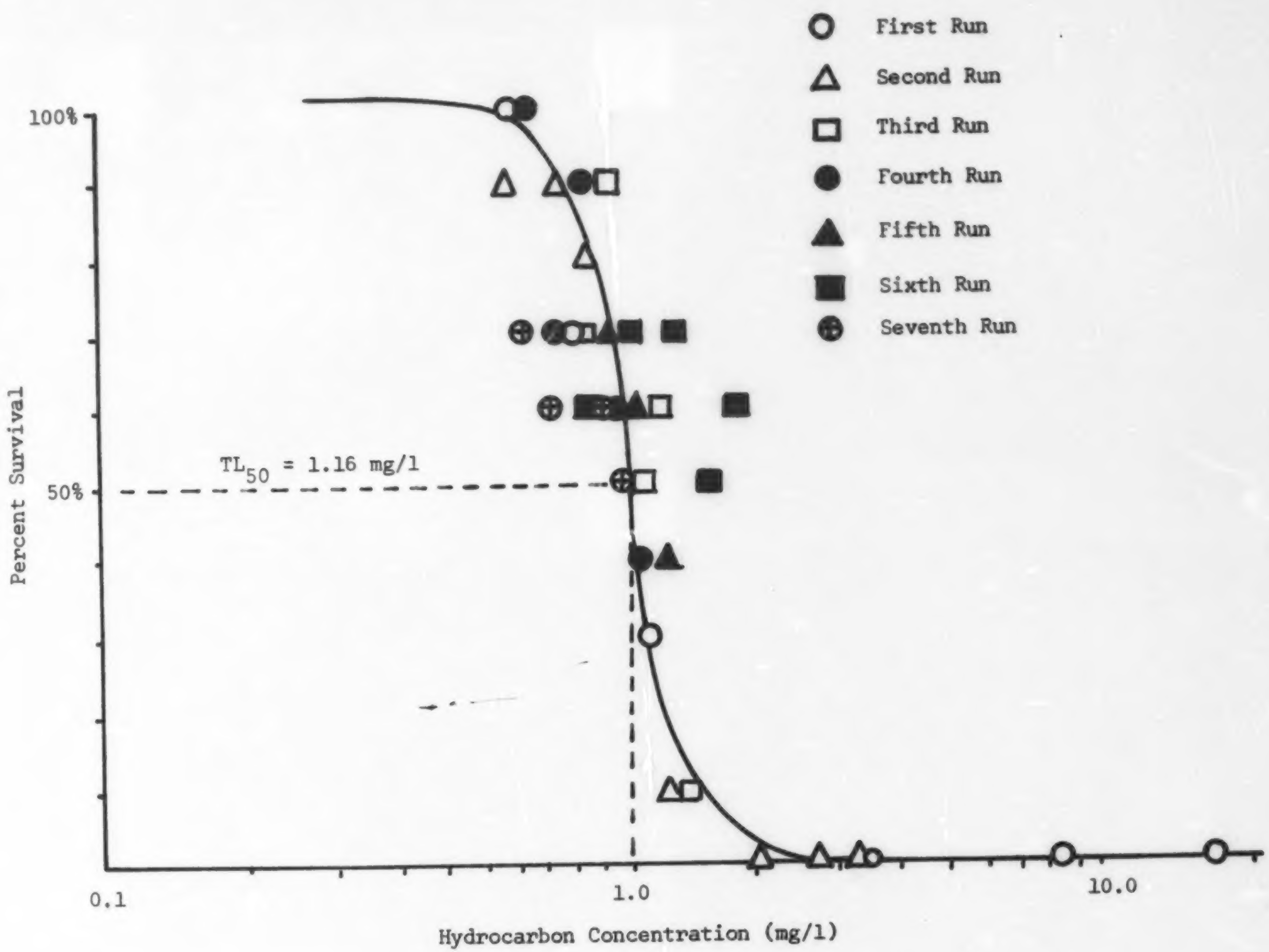

Figure 47 - 24 hr TL_{50} for Gammarus fasciatus

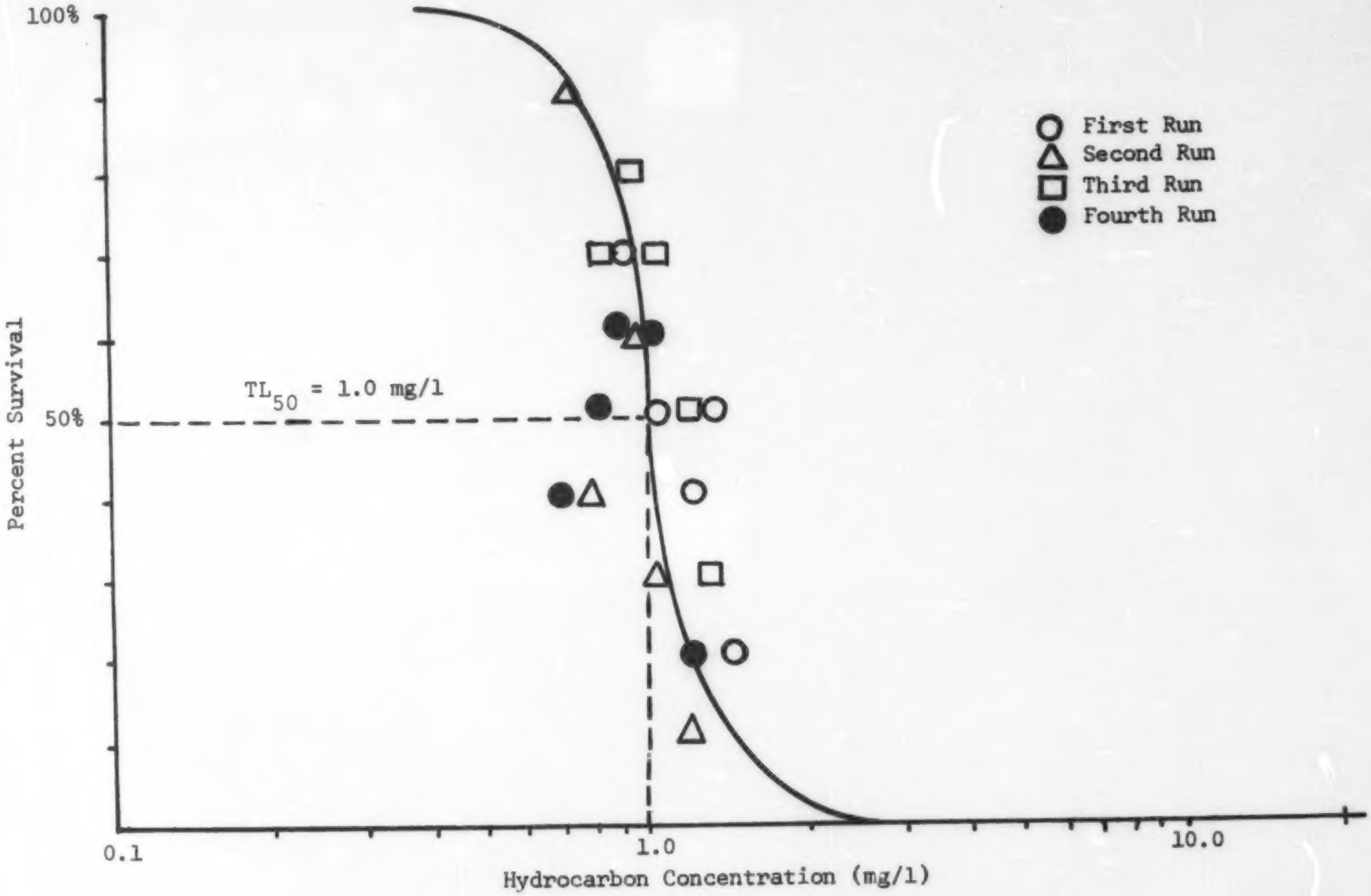

Figure 48 - 48 hr TL_{50} for Gammarus fasciatus

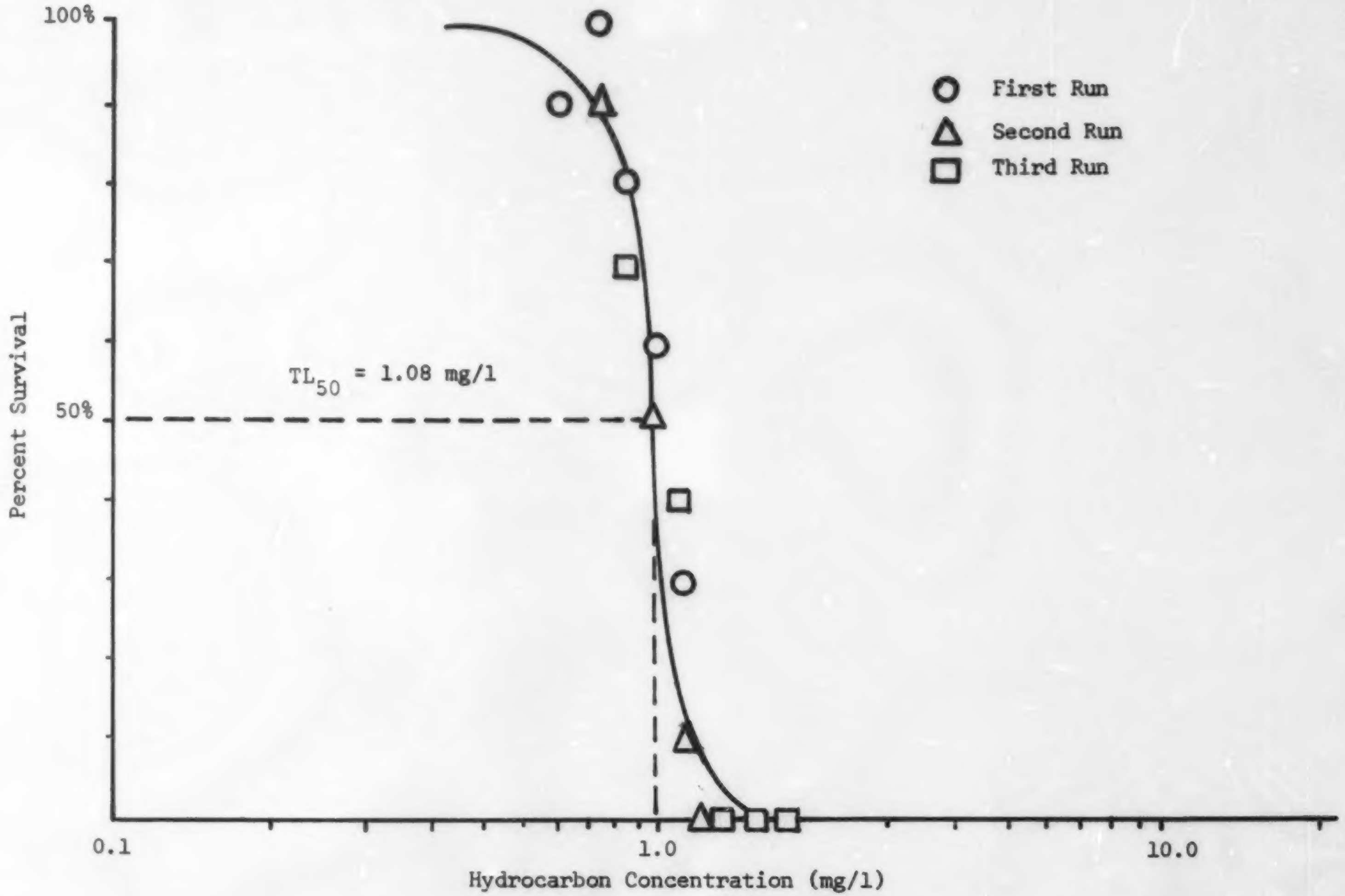

Figure 49 - 24 hr TL_{50} for Amnicola limnosa

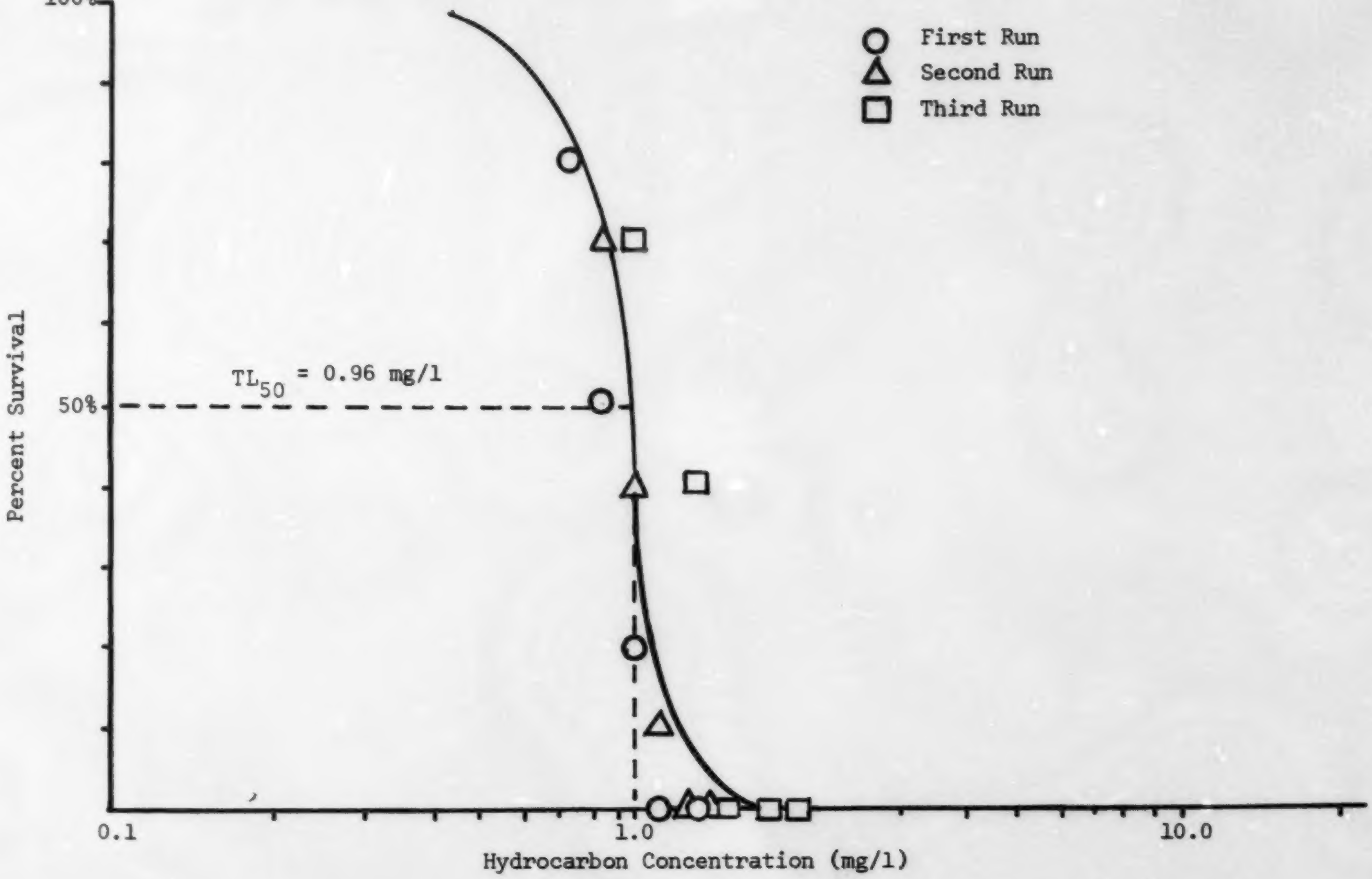

Figure 50 - 48 hr TL_{50} for Amnicola limnosa

more suitable to many burrowing worms, dipterans and aquatic insects. Echo Bay consistently had a relatively sparse dipteran fauna which may be due at least in part to the higher percentage of clay in the bottom sediments. According to Pagel (56) clay sediments yielded far fewer dipterans than either silt or sand substrates. Cole (16) has reported that the majority (70%) of benthic fauna are found in the upper 1 centimeter (cm) of bottom deposits. Also, deeper sediment layers contain less oxygen and may account for faunal distributions on the surface layers (Humphries (33)).

The water depth sampled ranged from 1.0 meter in Smith Bay to nearly 7.0 meters in Dunham Bay. Differences in taxa and seasonal variations seem to be depth dependent in many cases. Eggleton (20) discusses the distribution of benthic forms as it varies with depth from season to season. In the present study, it was noted that the highest populations of midges and other aquatic insects occurred earlier in the shallow areas (March to May) than at deeper stations (May to June), such as Dunham Station No. 3 and Smith Station No. 2. These maxima occurred just prior to the emergence of adults. The controlling mechanism also may be linked to a critical temperature which takes longer to be reached in deeper areas. In the case of midge larvae, several lesser populations were observed at the deeper stations. Apparently this is due to the fact that the number of generations per year varies in different species and depends in part on the depth and temperature of their habitats (Kendeigh (37)). In Smith Bay for example, three distinct maxima in the dipteran, Polypedilium were seen. More commonly, each month was dominated by a different dipteran group indicating some variation in emergence time among species. A similar pattern was noted by Pagel (56) for the bays of Lake Champlain. In general, the seasonal variations in both transitory fauna (insects) and permanent fauna (mollusks, worms, and crustaceans) after May followed the patterns described by Humphries (33) and many others.

Aquatic vegetation is known to affect the distribution of benthic fauna. Extensive examinations have been made on the relationships of benthic fauna distribution and aquatic vegetation as a nutrient source and/or cover (Berg (5), Walshe (90), Moon (48), Menon (46)). The submerged vegetation was greatest in variation in Dunham Bay. Dense beds of Potamogeton developed in May and were well established by June. Maximum populations of amphipods, Gammarus and Hyalella, and the isopod, Asellus, were due to early instar juveniles. The abundance of these forms occurred after the establishment of dense beds of submerged vegetation in the bays. At Smith Bay Station No. 1, where vegetation was limited to only small clumps, relatively few crustaceans were found.

Currents and wave action also affect faunal distributions (Odum (52) and Reid (61)). The streams entering Dunham Bay and Smith Bay seemed to play a role in the deposition or removal of substrate materials. In addition, Smith Bay was particularly exposed to the effects of wind and often experienced considerable wave action along the sandy shore near Station No. 1. Predation also regulates benthic populations and is considered one of the more important (Needham (51) and Swift (84)).

Hayne and Ball (31) and Hall (28) have studied the effects of predation on the density of benthos in experimental ponds and estimated that due to predation the actual production of an ecosystem may be many times greater than that resulting from instantaneous measurement (standing crop). In Lake George, fish such as bass, perch and sunfish were observed to spawn in late May through early June and the offspring remain in the bays through July. Predation along with insect emergence may play a major role in the decreased abundance of benthic fauna throughout the summer months.

The major physical and chemical parameters measured did not seem to exceed the limits suggested by Macon (43) and others for various sensitive aquatic insects. Dissolved oxygen reached 5.2 and 4.7 mg/l at the deeper stations in Smith and Echo Bays in May prior to the spring overturn which appeared to occur on the lake in late May or early June. This did not appear to have a significant effect on the benthic fauna whose density and relative abundance were high. Dissolved oxygen values were usually above 6.0 mg/l and temperature, pH and alkalinity were within accepted limits for aquatic organisms. Clesceri and Williams (15) and Bloomfield (6) reported that diatom assemblages in some portions of the southern end of Lake George are indicative of abnormal nutrient levels and related to population concentrations and presumably sewage effluents. In addition, Kremer (40) reports that high concentrations of hydrocarbons were found in Dunham Bay when compared with Echo and Smith Bays. While these may be causing subtle changes in the benthic fauna, they did not seem to be having noticeable effects. In general, the diversity of fauna in Dunham Bay exceeded that of both Smith and Echo Bays.

The results in Tables 41-48 indicate that these shallow bays have similar assemblages composed of diverse fauna. Of the total number of taxa identified, at least 22% appear to be common to all stations and 43% were found in all bays. Less than 20% of the total taxa were limited to only one bay. Most of the latter were uncommon representatives of the dipteran larvae or water mites (Acari) which were found in low numbers in only one or two dredge hauls. The greatest number of taxa were obtained from Dunham Bay and the least from Echo Bay.

All the major benthic faunal orders were well represented in each bay including "intolerant" groups such as mayflies, caddisflies, scuds and clams. In addition, "tolerant" groups such as certain annelid worms (Tubifex and Limnodrillus) and snails (Physa and Lymnea) were commonly found. The common occurrence of many forms generally considered sensitive to environmental stress indicate the absence of conditions which might limit such faunal diversity. More specially, the burrowing mayfly, Caenis, the caddisflies, Polycentropus and Leptocella, the amphipods, Gammarus and Hyalella and the clam, Pisidium, were commonly found in all locations.

The abundance or density of macroinvertebrates fluctuated considerably throughout the sampling period which is likely due to the emergence of aquatic insects in the spring or early summer. At the shallow stations, dipteran populations peaked between March and May 1972, immediately prior to and after ice out. At the deeper stations maximum values were noted between May and June followed by a similar drop due to insect emergence. Again, temperature dependence for the initiation of adult dipterans is likely. Other aquatic insects were most abundant in May at all stations prior to their emergence as adults in late May and June. The density of organisms in all bays averaged higher than reported for Lake Windermere, England (Moon (48), Humphries (33)) and for Lake Simcoe, Ontario (Rawson (60)); the number of taxa identified was higher than reported by these investigators for the littoral zones of other oligotrophic lakes.

Moon (48) stated that Lake Windermere was undergoing an oligotrophic to mesotrophic transition based on the abundance of Tanytarsus sp. and on a lesser number of Chironomus midge larvae equipped with auxiliary gills. In Lake George, several species of Tanytarsus were common. In addition, although species of Chironomus were common, only one of those identified possessed the auxiliary ventral gills considered indicative of oxygen depletion and eutrophic conditions. Ruttner (62) similarly stated that oligotrophic lakes were characterized by the presence of Tanytarsus whereas eutrophic waters were dominated by Chironomus. Most of the dipteran genera in Lake George were "clean water forms" as defined by Macon (43).

These studies showed diversity indexes ($\bar{d}$) to be generally around 3.0. The most notable exceptions were those for Smith Bay No. 1 and Dunham Bay No. 1, which averaged 2.358 and 2.804, respectively. Smith Bay Station 1 is in shallow water (1 meter); is exposed to considerable wave action; and the substrates are unconsolidated sands. The lower diversity indices computed for many stations from June through August were probably due to the emergence of insects or migration to deeper waters as described by Eggleton (20) and not representative of the true variety in fauna.

An additional factor must be considered when comparing the diversity index ($\bar{d}$) values obtained in this study with the range of values developed by Wilhm (93). Wilhm's scale of values was derived primarily from water quality studies in flowing waters. According to Odum (52) and Reid (61) lotic (flowing waters) conditions favor a annelid worms (*Tubifex* and *Limnodrillus*) and snails (*Physa* and *Lymnea*) were commonly found. The common occurrence of many forms generally considered sensitive to environmental stress indicate the absence of conditions which might limit such faunal diversity. More specially, the burrowing mayfly, *Caenis*, the caddisflies, *Polycentropus* and *Leptocella*, the amphipods, *Gammarus* and *Hyalella* and the clam, *Pisidium*, were commonly found in all locations.

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Dunham Bay No. 1 is a rather shallow station and appears to receive silt from Dunham Bay Brook and the marsh which it drains. It had a low mean diversity index and only 56 taxa were identified. High levels of hydrocarbons ranging from about 30 to 42 $\mu l/m^2$ from the boat activity in the brook have been noted by Kremer (40). Dunham Bay Station No. 2 is located just offshore from a large marina and high hydrocarbon values should be common in the area; however, it had a high mean diversity index (3.278) and the highest number of taxa (92). It would seem unlikely, therefore, that it should not be similarly effected if petrochemicals were limiting at Station No. 1.

In summary, the diversity indices for all bays exceeded or bordered the values considered indicative of unpolluted waters. The taxonomic variation was extremely high and contained many forms generally considered intolerant of nutrient loadings and toxic conditions. There was, however, high abundance compared to data for other oligotrophic lakes. Table 51 serves to compare the three bays on the basis of these three criteria. With the exception of Station No. 1, Dunham Bay is high in diversity and population density. Smith Bay Station No. 2 appears to have the most desirable characteristics from a biological point of view having high taxonomic variation (diversity) and population density. Echo Bay has a moderate diversity but low density. It must be remembered that abundance alone is not indicative of desirable conditions. On the contrary, low diversity and high density is characteristic of most highly enriched environments. Low abundance and low diversity may be indicative of toxic conditions (Cairns and Dickson (9)). Smith No. 1 had low diversity and high abundance. This was judged to be less a factor of water quality than of other environmental factors, such as lack of vegetation, shallow depth and unfavorable substrate. Dunham Bay Station No. 1 was similar to Nos. 2 and 3 in population density and had more taxa associated with it than either of the Echo Bay stations. The diversity index was only slightly below that assigned to unstressed waters.

Table 51

Comparison of Pertinent Parameters for the Stations Studied*

	Stations						
	Smith 1	Smith 2	Dunham 1	Dunham 2	Dunham 3	Echo 1	Echo 2
Diversity Index	7	1	6	2	3	4	5
Taxonomic Variation	4	2	5	1	3	6	7
Population Density	2	1	4	5	3	7	6

*Rating on a number line from 1 = highest to 7 = lowest

The hypothesis that the benthic community of Dunham Bay might be affected by the discharge of hydrocarbons from two-cycle marine engines is not supported by the field studies. The benthic community is markedly similar to that of the other bays considered. In some ways, a more diverse faunal assemblage is indicated.

It is felt that variations among the bays and individual stations studied at Lake George can best be attributed to natural factors such as bottom type, vegetation and depth rather than the direct influence of exogenically introduced materials. It is likely that the shallow bays are in a more advanced nutrient state than are the deep profundal areas. This is expected, however, since the accumulation of nutrient rich matter, such as detritus, occurs in such areas more rapidly. In addition, shallow areas contain greater numbers of rooted aquatics and other producers which enhance the available nutrient pool considerably.

Static Bioassays

It must be stressed that the static bioassays conducted on selected benthic fauna were preliminary in nature and were intended only to obtain estimates of the actual acute toxic lethal mean (TL_{50}). The exhaust waters tested contained materials which were both biodegradable and highly volatile. For such materials, the National Technical Advisory Committee (50) suggests continuous flow bioassays as the first choice. In addition, the materials in the exhaust waters appear to be toxic. The Advisory Committee again suggested continuous flow bioassays for materials toxic at concentrations of 1 mg/l or less, because the quantity taken into the organisms may be a very large percentage of the amount in the test waters. The static test can give useful relative measures of toxicity but should not be expected to yield absolute values on which to base standards.

Secondly, it is important to note that acute toxicity is quite different from chronic effects. It is possible that concentrations which are not lethal may affect reproduction or other behavior. Acute toxicity is a measure of what concentrations of a substance will kill an organism in a limited time.

According to Warren (91) and others the toxic effects of substances vary according to the chemistry of the water in which the test is conducted. Temperature, dissolved oxygen and other environmental conditions may affect toxicity. The use of standard freshwater as a dilutent was an attempt to standardize conditions. The resulting data are not necessarily applicable to all aquatic ecosystems. Due to the use of small organisms in a large volume of water, an air conditioned laboratory and a standard test solution, the effects of such variables was diminished.

The concentrations of CCl_4 extractable hydrocarbons were in the range of those reported by Shuster (69) and others. In each run, the resulting concentrations in a subsurface sample was about 30.0 mg/l, indicating consistency in engine efficiency and the spectrophotometric analysis.

The curves (Figs. 47-50) for the various TL_{50}'s are symmetrically sigmoid and the median portion is almost linear. In addition, the range of effects is quite narrow. These characteristics are identical to those described by Warren (91) for the theoretical cumulative frequency distribution curve of survival at various concentrations of a highly toxic substance.

It is likely that the values obtained are a reasonable approximation of the TL_{50} for exhaust water in the test environment. They are probably of the order of magnitude which might cause similar effects in Lake George.

The TL_{50} is a measure of acute toxicity or that level of material which kills 50% of the test organisms in a prescribed time limit. It is by no means a safe level for the organisms. The TL_{50}'s estimated for Gammarus fasciatus and Amnicola limnosa are remarkably small in range for both 24 and 48 hour periods. All values were close to 1.0 mg/l.

Pickering and Henderson (58) found that in bioassays using petrochemicals, the differences in the mortality of fish resulting from 24 hour or 48 hour exposures to the same concentrations were small. Apparently the range of TL_{50}'s is not broad and the 96 hour TL_{50} for the test organisms does not differ markedly from that for 24 or 48 hour periods.

The National Technical Advisory Committee suggests that harmless concentrations for various chemicals be derived from specified "application factors". The first of these is a ratio between known safe concentrations for continuous exposure and the known 96 hour TL_{50}. To calculate the harmless level, one multiplies the 96 hour TL_{50} by the application factor. In the bioassays on exhaust water's survival was high, below a value of 0.6 mg/l. We can approximate the 96 hour TL_{50} at 0.9 mg/l. By assuming these values are representative, the ratio (0.6/0.9) or application factor would be 0.66 and the safe level approximately (0.66 x 0.9) 0.59 mg/l. A second application factor involves a fixed percentage of the 96 hour TL_{50}. For non-persistent materials a concentration of not more than 1/10 the 96 hour TL_{50} is advised. For persistent materials from 1/20 to 1/100 may be safe.

An additional consideration involves the possibility that any possible effects from hydrocarbon discharges may occur initially in the deeper waters of the lake. Surber (82) suggests that while the shoreward zones of vegetation contain a greater variety of organisms, the photosynthetic activity of plants and the circulation of surface waters are likely to create better living conditions in the zone of vegetation than exist in waters deeper than about 15 feet. In this way, organisms in deeper waters may be more readily effected by discharge than those in shallow bays.

SECTION VIII - ADSORPTION OF EXHAUST PRODUCTS ON BOTTOM SEDIMENTS

INTRODUCTION

As an aid to establishing the fate of exhaust products discharged to lake water, it was desirable to determine the ability of bottom sediments in suspension to adsorb the products. Consequently, tests have been made to determine the relative ability of the sediments from the test bays to pick up these materials and carry them to the bottom.

In addition, a qualitative study of the aliphatic hydrocarbons in the lake sediments has been made. This study was felt to be of interest for several reasons, mainly:

a) These compounds have been detected by other investigators in marine and fresh water sediments.
b) These compounds are normal constituents of gasoline and oil.

Thus, this study was intended to identify constituents present in the sediments and to relate them to hydrocarbons normally found in gasoline and oil. It also was felt that the analytical techniques investigated for this work could be evaluated and could provide a background of experience for other aspects of the study.

HISTORICAL REVIEW

In recent years there has been a considerable amount of research done on the distribution of oil from spills in the environment, but relatively little on the specific mechanisms of adsorption of oil and related materials on suspended sediments. Holcomb commented on research by Soviet microbiologists on the fate of an oil spill on the Moskva River in 1950 (32). Upon spillage of this nature, the volatile fractions evaporated and the residue was adsorbed by particulates and sand. Microorganisms in the sediments acted upon these compounds and the product of the degradation floated with methane and other gaseous end products. These compounds were again adsorbed and sank to be further degraded by benthic microorganisms.

Other work describing research related to the distribution of oil in the environment has been descriptive in nature (47,32,25).

Hamilton studied the effect of turbulence, soil size and the amount of oil present on the adsorption of various types of soils suspended in water (29).

Comparatively little research effort has been expended on the hydrocarbon analysis of sediments. Although some studies were carried out during the 1960's, the majority of such studies were done at an earlier date. This work was directed primarily at studying the origin of petroleum.

Antonetti-Alvarez has presented an extensive review of analytical techniques used in this area (1).

PROCEDURE

The methods used for the adsorption studies were essentially modifications of methods described by Hamilton (29). Samples of sediments were collected from the bays by a dredge, filtered and weighed. Sample weights were corrected for moisture content as determined separately. Direct drying of samples produced very hard samples which had to be pulverized. Direct drying was, therefore, not used after preliminary work.

Sediment samples were added to 1800 ml of water in two-liter beakers. Measured quantities of liquid exhaust products collected from test outboard engines were added to each beaker. The beakers were placed in a standard Phipps-Bird jar test apparatus and agitated at about 90 RPM for two hours. Previous work had indicated that this speed appeared to be optimum. A range of speeds appeared to have almost no effect on absorptive properties. The quantity of exhaust products added were 0.05, 0.10, 0.20, 0.50, and 1.00 ml to the beakers. These quantities corresponded to 3, 6, 12, 30, 60, and 72 ml/square meter of surface. The agitator blade was positioned about 1 cm below the water surface, as recommended by Hamilton. (Fig. 51)

Aliquot samples of sediments were removed by suction to avoid bringing the sediments in contact with surface material. A siphon arrangement was used to draw off samples as shown in Fig. 52. The samples were filtered, weighed and placed in a Soxhlet extraction thimble and extracted. Anhydrous sodium sulfate was placed in the flask to remove water. The salt was filtered out before evaporation of the solvent. In preliminary work, hexanes were used as the solvent, but were replaced by methylene dichloride. This solvent proved to be much more effective and generally satisfactory. Solvent was evaporated in a rotary evaporator under a vacuum. The residue remaining in the flask was weighed. Blanks were run on each sediment to determine the solvent extractables.

In the work directed at hydrocarbon identification, most of the analytical work which was done was aimed at isolating the aliphatic (saturated) compounds from the myriad of other compounds which form sediment. Figure 53 graphically depicts in block form the procedure followed. The analytical procedure may be divided into five phases:

a) Sample Preparation
b) Total Organic Carbon Determination
c) Soxhlet Extraction
d) Liquid Chromatography
e) Gas Chromatography

Sample preparation involved a sequence of four steps, mainly: sample characterization, filtering, drying, and grinding. These steps consisted basically of methods aimed at removing extraneous material from

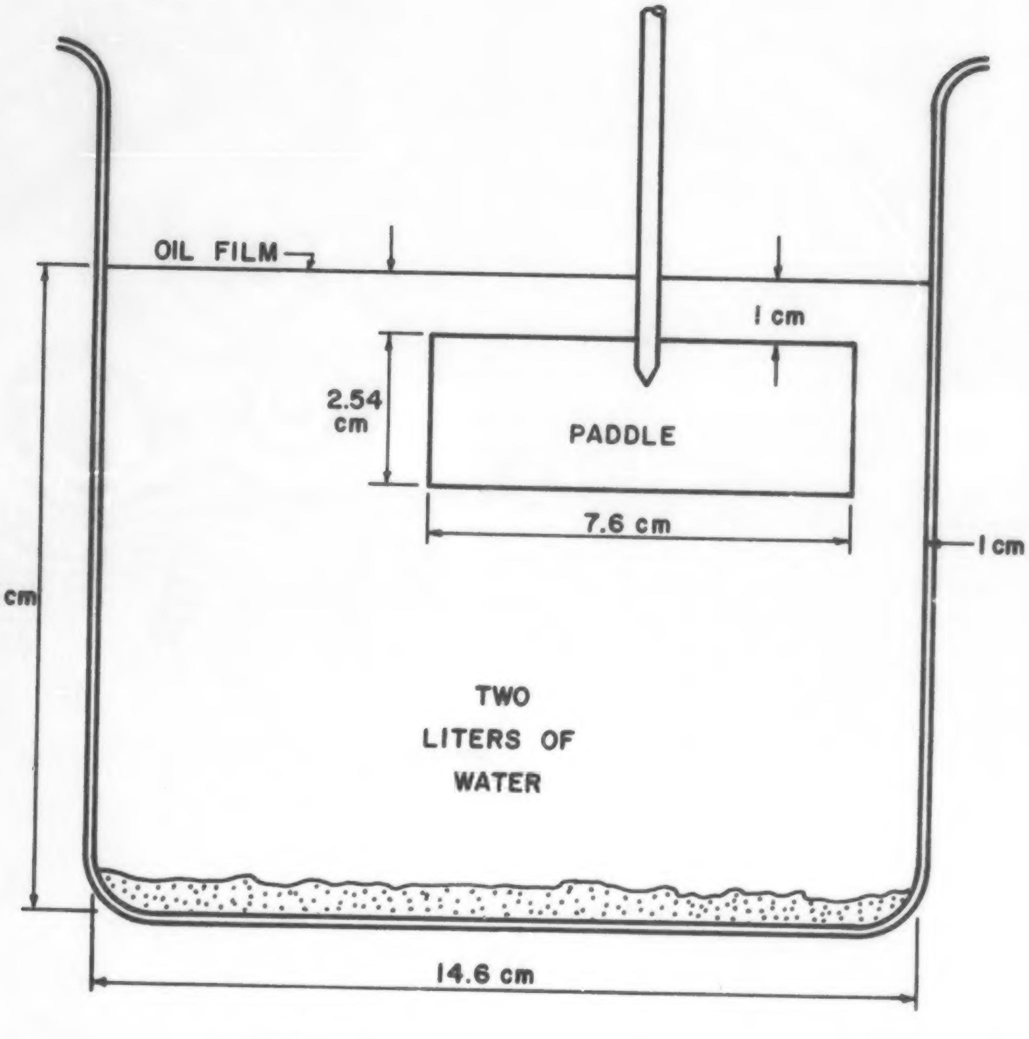

OIL FILM
1 cm
2.54 cm
PADDLE
7.6 cm
1 cm
11 cm
TWO LITERS OF WATER
14.6 cm

Figure 51 - Jar Test Apparatus

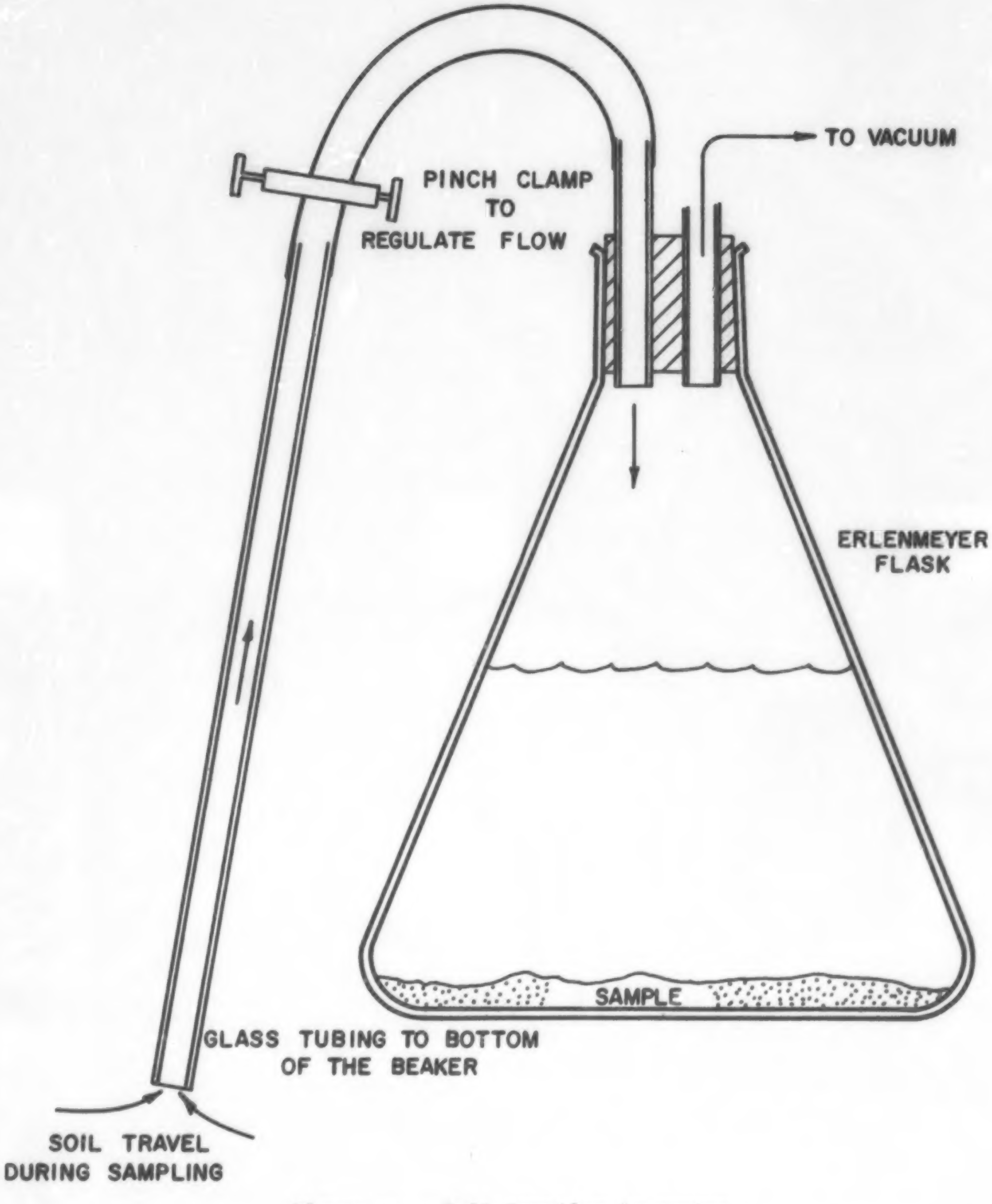

TO VACUUM
PINCH CLAMP
TO
REGULATE FLOW
ERLENMEYER
FLASK
SAMPLE
GLASS TUBING TO BOTTOM
OF THE BEAKER
SOIL TRAVEL
DURING SAMPLING

Figure 52 - Soil Sampling Apparatus

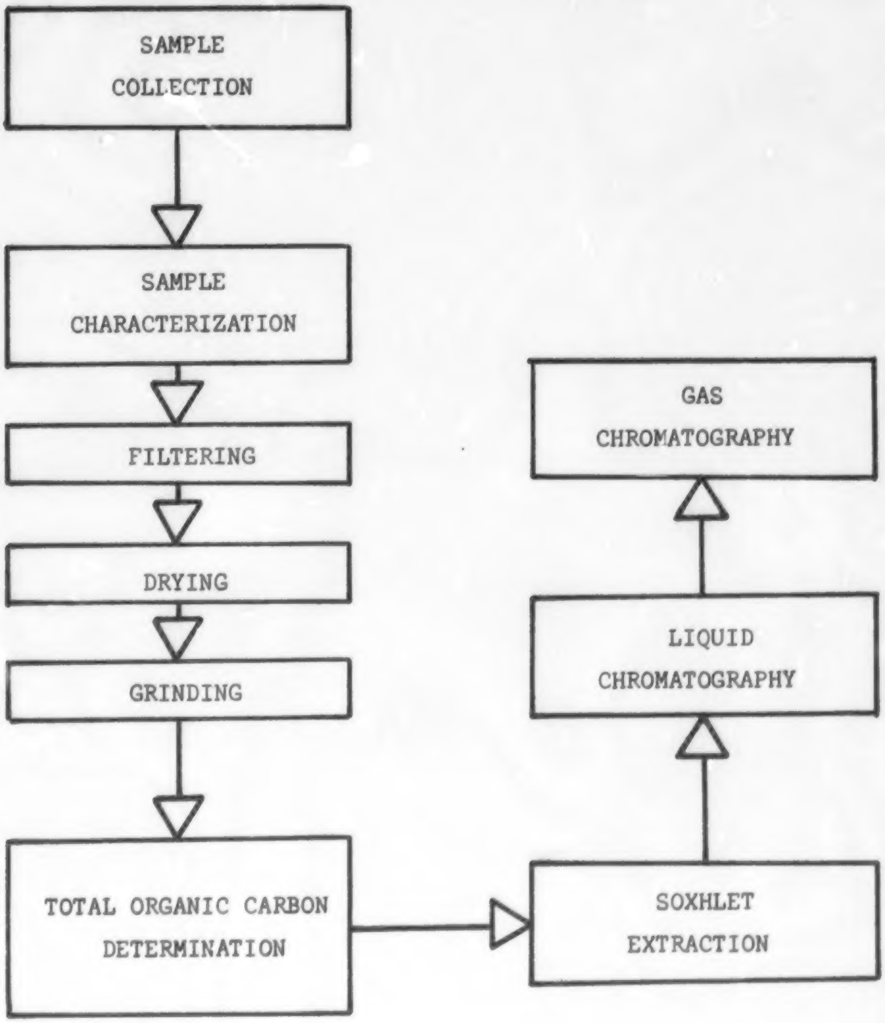

SAMPLE COLLECTION
SAMPLE CHARACTERIZATION
FILTERING
DRYING
GRINDING
TOTAL ORGANIC CARBON DETERMINATION
SOXHLET EXTRACTION
LIQUID CHROMATOGRAPHY
GAS CHROMATOGRAPHY

Figure 53 - Analytical Procedure Used in This Study

the sediment (animals, bottom plants, whole leaves, etc.), washing the sediment with distilled water in order to effect a partial removal of soluble organic compounds and inorganic (salts) - since these compounds are not of interest here. The sediment was then air-dried with dry air at room temperature, and it was finally ground with mortar and pestle to approximately a 60/200 mesh size.

The next step was a determination of the total organic content of the sediment samples. The method of Schollenberger (68) as later modified by Purvis and Higson (59) was used for this purpose. In this project this method was modified slightly in order to make it more useful and faster; also, a new way of analyzing the data obtained by using this method was devised.

Following the total organic carbon determination, the dry sediment samples were then extracted in a Soxhlet extractor with a CCl_4, C_6H_6, CH_3OH mixture during 24 hours. Normally 160 mg of this mixture was used in the extraction. The extract obtained by this procedure ranged in color from golden to almost black. The extract residue was isolated by blowing dry air into the flask with the sediment extract until all of the excess solvent had evaporated. Usually around 0.1-0.8 g of extract residue was obtained per 18-40 g of air-dried sediment.

This residue was then dissolved in n-heptane and forced onto a column of activated alumina previously prewetted with n-heptane. The column was eluted with 5-10 ml fractions of n-C_7 followed by 10-10 ml fractions of CCl_4. The material eluting with these two compounds was collected (in same flask), according to Smith, Bray and Evans, and Kvenvalden (70,7,41). Dry air was then passed into the flask containing this eluate fraction, and the excess solvent mixture was removed. The residue thus obtained was then dissolved in toluene and analyzed on a gas chromatograph (F & M 810, FID, single column) using n-decane as reference.

RESULTS

The results of the adsorption tests on sediments have been summarized in Table 52, and are plotted in Fig. 54.

Figures 55 and 56 show the results of the gas chromatographic runs of two of the samples tested. Table 53 shows the normal alkanes identified in each sediment batch. Table 54 gives the peak number (a set of numbers, in sequence, given to each peak for accounting purposes) of the five largest peaks on each chromatogram - when the identity of the peak is known, the number of carbon atoms are given in parenthesis. This table also gives the total number of peaks on which identification was attempted.

DISCUSSION

It can be seen from the results listed in Table 52 and plotted in Fig. 54 that the amount of exhaust products adsorbed on lake sediments

Table 52

Summary of Adsorption Results

Exhaust Products Added ml/sq Meter	gms Extract per gm Soil Collected	Blank gms Extract per gm Soil	Net gms Extract per gm Soil Collected	Total gms Extract to Soil
Echo Bay Samples, Dried and Pulverized Exhaust Products from 33 Hp Evinrude @ 1200 RPM Solvent-Hexanes				
3	0.0041	0.0008	0.0033	0.0189
6	0.0030	0.0008	0.0022	0.0137
12	0.0022	0.0008	0.0014	0.0094
30	0.0074	0.0008	0.0066	0.0451
120	0.0313	0.0008	0.0305	0.1560
Echo Bay Samples, Filtered Exhaust Products from 9.5 Johnson @ 1000 RPM Solvent-Methylene Chloride				
3	0.00220	0.00139	0.00081	0.00027
6	0.00384	0.00139	0.00245	0.00697
12	0.00261	0.00139	0.00122	0.00899
30	0.01509	0.00139	0.01370	0.00555
60	0.01210	0.00139	0.01071	0.0532
72	0.01740	0.00139	0.01601	0.0851
Dunham Bay Samples, Filtered Exhaust Products from 9.5 Johnson @ 1000 RPM Solvent-Methylene Chloride				
3	0.0307	0.0041	0.0266	0.0268
6	0.0273	0.0041	0.0232	0.0341
12	0.0200	0.0041	0.0159	0.0267
30	0.0289	0.0041	0.0248	0.0432
60	0.0312	0.0041	0.0271	0.0385
72	0.0387	0.0041	0.0346	0.0488

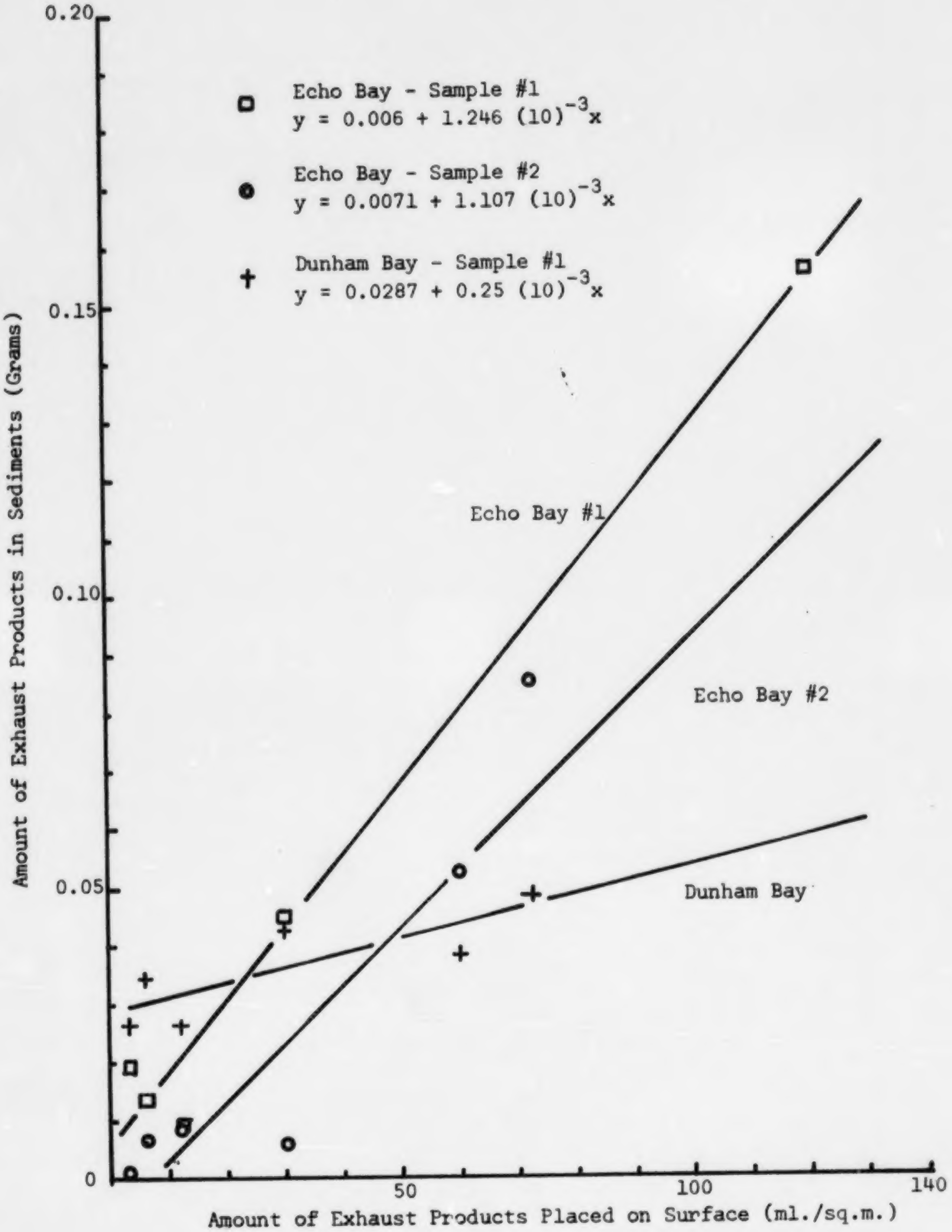
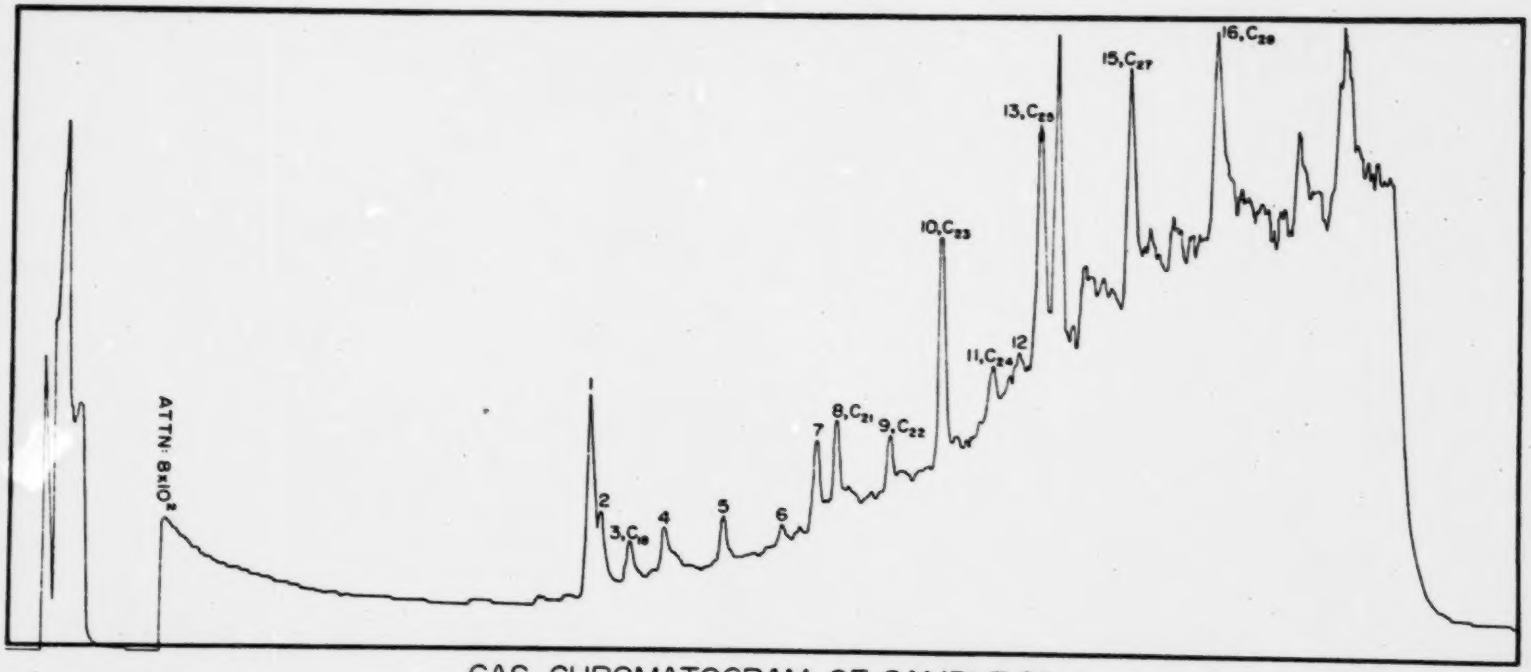
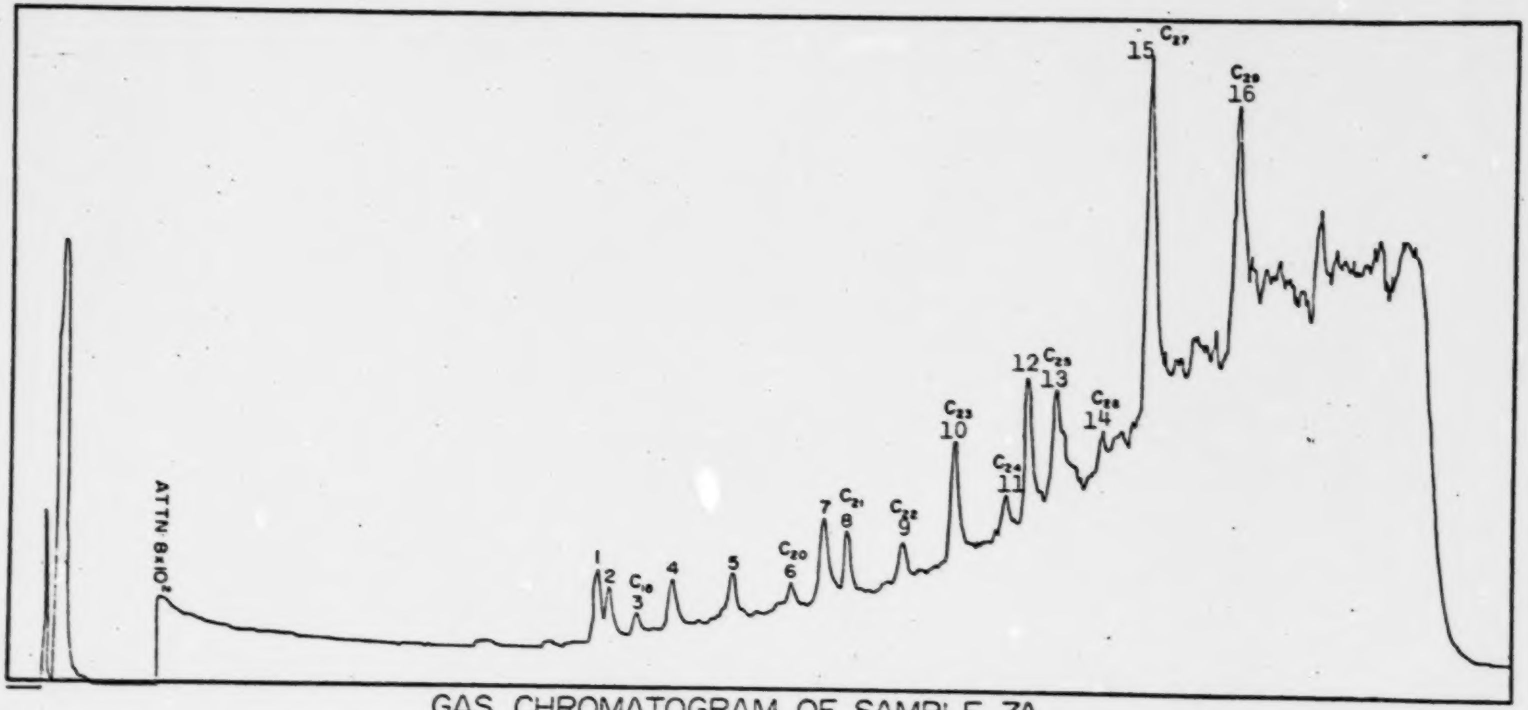


Figure 54 - Amount of Exhaust Products Adsorbed in Sediments vs Amount of Exhaust Products on Water Surfaces



GAS CHROMATOGRAM OF SAMPLE 4A

Figure 55



GAS CHROMATOGRAM OF SAMPLE 7A

Figure 56

Table 53

Normal Alkanes Identified in Each Sediment Extract

Compound	Sample Numbers
Octadecane	3A, 4A, 7A, 8A
Nonadecane	10A
Eicosane	7A, 8A, 10A
Heneicose	1A, 4A, 7A, 8A, 10A
Docasane	1A, 3A, 4A, 7A, 8A, 10A
Tricosane	1A, 4A, 7A, 8A, 10A
Tetracosane	4A, 7A, 8A
Pentacosane	1A, 4A, 7A, 8A, 10A
Hexacosane	1A, 4A, 7A, 10A
Heptocosane	1A, 4A, 7A, 8A, 10A
Octacosane	1A, 4A
Nonacosane	1A, 7A, 8A, 10A

Table 54

Five Largest Peaks Detected in the Sediment Extracts

Sample Number	Five Largest Peaks	No. of Peaks Between 100°C-340°C
1A	1; 7; 8; 5; 13(22)	22
3A	6; 8; 9; 12(22); 11	13
4A	14; 13(25); 15(27); 10(23); 16(28)	16
7A	15(27); 16(29); 12; 10(23); 13(25)	18
8A	15(29); 14(27); 10(23); 13(25); 4	15
10A	16(27); 18(20); 13(25); 11(23); 9(21)	18

Numbers in parentheses are the carbon numbers corresponding to the indicated peaks.

increases with the amount. This is consistent with the results of Hamilton made with various types of soils. It also can be seen that the sediments in Echo Bay seem to have a much higher tendency to adsorb the exhaust products, than do those from Dunham Bay. This may be related to the nature of the sediments in the bays. The sediments in Echo Bay seem to be characterized by a high clay content and a low organic material content. The sediments from Dunham Bay are much higher in organic matter and more heterogeneous in composition.

It is noticeable, from the data in Fig. 57 which represents the relative amounts of n-alkanes in a variety of products as presented by Stevenson from the data of other investigators, that there seems to be a prevalence or predominance of odd-numbered hydrocarbons over even-numbered hydrocarbons in natural occurring systems.

In Fig. 57 Stevenson has shown relative amounts of n-alkanes in pasture plants, manure, soils, recent sediments, and crude oil, from the work of other investigators (75). It is readily seen that sediments, soils, and extracts from land plants and cattle manure show a definite predominance of odd-numbered hydrocarbons, while crude oil shows no such preference. These considerations suggest that the hydrocarbons detected in Lake George sediment extracts are "native" or natural to these sediments - that their presence in the sediment was not due to man-induced sources. Although this odd-numbered normal alkane preference of sediments is well-established, there is still some debate about it. Koons, et al. found no significant odd-numbered normal alkane preference in the sediments which they tested (39).

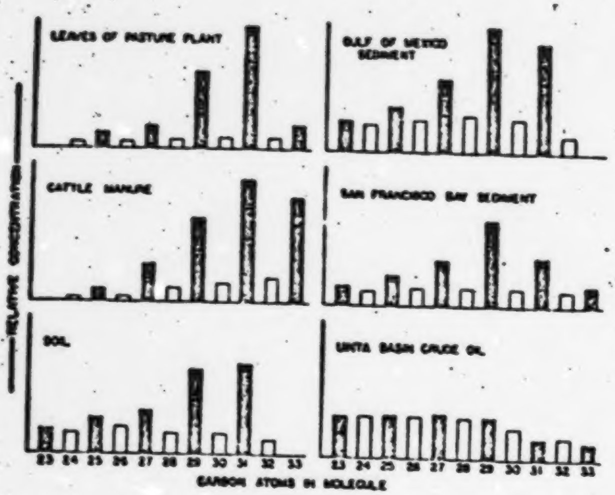


Figure 57 - Relative Amounts of N-Alkanes in Pasture Plants, Manure, Soils, Recent Sediments, and Crude Oil, from Reference 75

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SECTION IX - TANK TESTS FOR COLLECTING EXHAUST PRODUCTS

A number of tests were made by operating a 33 H.P. Evinrude engine in a test tank. The purposes of these tests were several. The primary purpose was to collect samples of exhaust products at various operating conditions for use in developing analytical procedures, and for use in the adsorption studies, evaporation studies and microbiological studies. The engine was run with and without an anti-pollution device attached. The device was not used in its normal way by recirculating the material usually disposed of through the puddle drain. Instead, the device was used as a means of collecting the exhaust products. Surface samples, water column samples and perimeter samples were collected for each run to determine the total amount of carbon tetrachloride extractable material which was added to the water during specified operating conditions.

The tests were run in a steel tank of 48 cu ft capacity. This tank was used to facilitate sampling and to make it easier to operate and clean. It was found, however, that while the expected advantages were indeed realized, its use had other disadvantages. The small size made it difficult to use other larger engines because of splashing. In addition, it was found that the tank water heated up somewhat as noted in Table 55. This may account for the lower values for the percent of fuel discharged found during these runs as compared to previously noted values (3).

Surface samples were collected and analyzed by the techniques described in Section IV. Samples were collected using the sampler shown in Fig. 5. Carbon tetrachloride was used for extraction and the samples were analyzed using infrared spectroscopy.

Water column samples were collected at a point approximately six inches below the water surface.

Perimeter samples were collected by cleaning a one foot section of the wall at the surface level with a measured amount of carbon tetrachloride and analyzing the extract.

Table 55

Tank Tests

Motors: 1968 Evinrude 33 H.P. in Good Condition

Run No.	RPM	Fuel Used Liters	% of Fuel Discharged	Initial Temp. °C	Final Temp. °C	Oil Concentrations Surface gms/12 ft^2	Oil Concentrations Tank g/36 ft^3	Oil Concentrations Perimeter mg 10 ft
1	1200	2.00	3.9	11	18			
2	2000	2.48	1.1	9	18			
3	4000	4.48	0.4	9	29			
4	650	1.56	10.7	10	14			
5	2000	2.32	1.1	10	21	385	85.5	126
6	4000	5.60	0.4	10	33			
7	600	1.73	*	12	16			
8	2000	2.55	*	10	21			
9	4000	5.40	*	12	32	244	11.4	418
10	650	1.84	*	11	16			
11	2000	2.48	*	12	22			

*Without anti-pollution device attached

SECTION X - THRESHOLD ODOR NUMBER TESTS

INTRODUCTION

With the increased usage of our natural waters for both drinking and recreational purposes, greater emphasis has been directed to the subjective quality criteria of water. Tastes and odors are quite apparent to homeowners and residents on recreational bodies of water such as Lake George. Use of the lake water for drinking, cooking and washing, as well as for swimming, boating, and other recreational purposes is widespread.

Many substances contribute to the taste and odor of water including most organic compounds and many inorganic compounds. Since many odorous materials are detectable when present in only a few micrograms per liter and are often complex, it is usually impractical and often impossible to isolate and identify the odor-producing material. The chemical senses of odor and taste are thus important in the evaluation of the levels of odor and taste-producing substances.

In recent years, numerous complaints of increased levels of odor have been made by residents at Lake George, particularly during the summer period. Residents have associated these odors, described as petrol-like, with the exhaust discharges from outboard engines. A study, therefore, has been made of the levels of odor experienced in the waters of Dunham, Echo and Smith Bays as a function of the time of year. For comparison a few tests were also made on water from a test tank in which an engine was run for various times. The effect of allowing samples to age was also examined to a limited extent.

BACKGROUND

The perception of odor has never been fully explained to the complete satisfaction of all investigators. It has been observed that an odor is perceived by humans when some substance capable of exciting the nerves reaches the specialized tissues of the olfactory tract high in the nasal vault and dissolves in the films of liquid covering the exposed surfaces of these tissues (80). The property of the dissolved substance which causes the nerves to transmit a sensation to the brain has not yet been found. Human response to odor is quite variable. A smell to one person may be a fragrance to another. It appears that when the odor stimulus is transmitted to the brain, we draw upon memory of past odors and match this stimulus with one of these odor memories.

In order for there to be a perceptible odor, a certain number of molecules or particles sufficiently small to be carried along with the air must reach the olfactory receptors. This number is determined by the size, shape, and polarity of the molecules (79). At the same time, these factors determine the specific odor of each molecule, so that there is an interdependence between odor threshold, the size and the smell of the molecular species. The odor threshold is defined as the lowest concentration at which one recognizes the odor.

For further information regarding the most recent theories on the mechanism of olfaction, books by Sumner (80,81), and reports to a symposium for the American Chemical Society (18) are most useful.

PROCEDURE

The tests used to determine the threshold odor number of water samples were conducted in accordance with procedures described in Standard Methods for the Examination of Water and Wastewater. All glassware used in these tests was specially cleaned using chromic acid cleaning solution and rinse water deodorized with activated carbon.

Water samples collected for examination were stored in cleaned glass containers and kept at low temperatures to preserve the odor quality of the water. Tests were performed as soon as possible after collection, generally four hours after collection but no more than 24 hours.

The test was conducted by placing a 200 ml sample of water in a 500 ml Erlenmeyer flask and allowing the flask and contents to achieve a constant temperature of 40°C in a constant temperature bath, and comparing the odor with that of a similar flask of odor-free water. When an odor was detected, its nature was recorded, and the sample diluted with odor-free water until an odor could no longer be detected. The last dilution at which odor is detected is defined as the threshold odor number, and is equal to the ratio of the volume of diluted sample (constant at 200 ml), and the actual volume of the original sample present in the diluted volume.

Odor-free water was prepared by passing double-distilled water through a column of activated carbon. Precautions were observed to air-condition the room in which tests were conducted, and to keep all odorous materials away from the room. All glassware was specially cleaned and rinsed with odor-free water. Checks on results were made periodically by using several individual testers.

Samples were collected in 16 oz wide-mouthed glass jars with plastic covers by lowering the containers to a point one foot below the surface, opening and filling the container, restoppering and removing the container. The same technique was used for all samples.

To investigate the severe effect outboard motor exhaust would have on the threshold odor number of water, outboard engines were run in a painted steel tank. The tank's dimensions were 3' x 3' x 4'.

The engines were recent models: an Evinrude 33 H.P. and a Johnson 9.5 H.P. Both engines were run with a 50:1 fuel to oil ratio. The Johnson was equipped with a device designed to recirculate liquid exhaust emissions. The Evinrude was equipped to either discharge exhaust products directly to the water, or to allow the liquid exhaust products to be collected as desired.

Before each test run, the tank was scrubbed with cleansers and rinsed to remove oil and odor-bearing water. A background sample was taken before the run was started. Water temperature was determined before and after each run.

In most cases the engine was run for 30 minutes. Samples were taken at intermediate times also. Total fuel consumption and engine speed were measured and recorded (88).

RESULTS

The results of running outboard engines at controlled speeds in the test tank are given in Tables 56 and 57. As seen from these results, the build-up of odors was severe under these conditions. It may be noted that the threshold odor number increased with time and with engine speed. Fuel usage also increased with engine speed.

All odors from these tests were characterized as slight petrol to very heavy petrol. There was no question as to the type of odor. A comparison of values when exhaust was discharged directly from the Evinrude, and when it was collected separately, showed lower odor numbers in the latter case. The larger engine generated higher odor numbers than the smaller engine.

An investigation was made of the effect of aging samples in open containers for various times, to simulate the lake surface exposed to the atmosphere. Results of these tests for both pre-aged and post-aged threshold odor numbers are given in Table 57. In all cases the threshold odor number was greatly reduced and in most cases the definite petrol odor was no longer detectable.

The results of the lake tests for the various sampling stations are given in Table 58 and are plotted in Figs. 58-64. It may be noted that the ranges given both in the tables and the figures represent the interval between the number corresponding to the last detectable odor, and the next succeeding number at which no odor was apparent.

The samples taken prior to early May were taken while ice was on the lake. These values in general were quite low. After the ice melted, the threshold odor numbers for Dunham Bay and Echo Bay showed increasing values as the summer progressed, and reached values as high as 38.1 and 32.0, respectively. Except for a brief sharp rise in June coinciding with an algal bloom, the values for Smith Bay tended to remain low, with small fluctuations in the range of 5 to 15.

Table 56

Threshold Odor Numbers for Outboard Motors Run in a Controlled Environment: Time and RPM. Evinrude 33 H.P. with Liquid Exhaust Collection and with a Test Propeller

RPM Time	600-700	1000	2000	4000
Background	8.0	14.2	7.1	7.1
1 minute	21.4			
3 minutes	32.0			
7 minutes	40.0			
10 minutes	95.0	852.0	2560.-5120.	850.-1130.
30 minutes	190.0	6880.-13333.	10240.-20480.	3200.-6400.
Fuel Usage (ml)	1565	2000	2480	4480
Initial Temp./Final Temp. (°C)	10/14		10/18	9/29

Note: All samples were characterized by strong petrol odors with the exception of 1 minute and 600-700 RPM which exhibited a slight petrol odor.

Table 56 (continued)

Threshold Odor Numbers for Outboard Motors Run in a Controlled Environment: Time and RPM. Evinrude 33 H.P. without Liquid Exhaust Collection (no control device) and with a Test Propeller

RPM Time	600-700	1000	2000 Recheck	4000
Background	5.33	10.7	14.2	5.33
1 minute	50.7	70.7	150.0	76.0
3 minutes	135.0	189.0	171.-228.	202.0
10 minutes	672.-900.	675.-900.	1010.0	2000.-2666.
30 minutes	4010.-5340.	1540.-2020.	2040.0	6050.-8060.
Fuel Usage (ml)	1730	2550	2650	5100
Initial Temp./Final Temp. (°C)	12/16	10/21	10/22	12/35

Table 57

Threshold Odor Numbers for Outboard Motors Run in a Controlled Environment: Time and RPM.
Johnson 9.5 H.P. with a Liquid Exhaust Recirculation Device. 1000 RPM

Background	3.15	4.0	10.7
10 minutes		20.-40.	28.4+ 26.6++
20 minutes		160.0	
30 minutes	80.-160.	133.-200.* 160.-200.**	
Fuel Usage (ml)	880		

*Sampled from under the surface of the water while air bubbles were rising.

**Sampled from under the surface of the water after waiting 15 minutes, no more air bubbles rising.

+Sample tested in usual procedure.

++Same sample but allowed to remain in an open container for 6 hours. Still a strong petrol odor.

Table 57 (continued)

Threshold Odor Numbers for Outboard Motors Run in a Controlled Environment. Tests for the Effect of Aging One Week in Open Glass Jars. Evinrude 33 H.P. with Liquid Exhaust Collection and with a Test Propeller. 600-700 RPM

	Immediate Testing	Aged One Week
Background	8.0 cleanser odor	2.0 musty odor
1 minute	21.4 slight petrol odor	4.64 musty, no petrol odor
3 minutes	32.0 stronger petrol odor	10.9 musty, very slight petrol odor
7 minutes	40.0 very strong petrol odor	18.25 musty, very slight petrol odor
10 minutes	95.0 very strong petrol odor	24.4 slight petrol odor
30 minutes	190.0 very strong petrol odor	64.0 definite petrol odor

Note: In all cases 1, 3, 7, and 10 minutes there was no petrol odor at all or it could not be detected after the first few dilutions. 30 minutes had a petrol odor that remained for a while.

In all cases 1, 3, 7, 10, and 30 minutes after the petrol odor could not be detected, they all maintained the same musty odor, similar to the background odor.

Table 58

Threshold Odor Number from March through July 1972

(The lower number of the threshold number range represents the last detectable odor number, while the higher number is the next successive odor number for which no odor was detected.)

Date	Threshold Odor Number Range	Odor Description
Dunham Bay Station 1		
3/21	3.4 - 3.97	algal odor
5/13	8.13 - 9.3	earthy odor
5/26	8.0 - 10.7	earthy-musty-fishy
5/29	8.46 - 11.3	faint fishy
6/5	10.7 - 14.2	earthy-grassy
6/9	9.45 - 12.6	earthy
6/12	18.9 - 25.2	earthy
6/16	18.9 - 25.2	sweet earthy
6/19	21.3 - 28.4	earthy
6/23	9.45 - 12.7	--
6/25	14.2 - 18.9	very earthy
6/30	14.2 - 18.9	earthy-grassy
7/1	14.2 - 18.9	earthy-grassy
7/3	38.1 - 50.7	strong earthy-fishy
7/4	33.5 - 44.7	distinctly earthy
7/6	28.3 - 37.7	very earthy
7/10	16.0 - 21.3	--
7/14	18.9 - 25.2	mild earthy
7/17	10.7 - 14.2	earthy
7/21	10.7 - 14.2	--
Dunham Bay Station 3		
3/21	6.17 - 7.06	algal
5/13	9.29 - 10.62	strong algal-fishy
5/26	7.05 - 9.47	earthy
5/29	6.34 - 8.46	faint earthy-fishy
6/5	10.7 - 14.2	earthy
6/9	12.6 - 17.0	earthy
6/12	14.2 - 18.9	earthy
6/16	21.3 - 28.4	sour earthy
6/19	25.2 - 33.5	earthy-slight fishy
6/23	9.45 - 12.7	strong earthy
6/25	10.7 - 14.2	--
6/30	10.7 - 14.2	earthy-fishy
7/1	10.7 - 14.2	--

Table 58 (continued)

Date	Threshold Odor Number Range	Odor Description
Dunham Bay Station 3 (cont)		
7/3	28.5 - 38.1	strong earthy-fishy
7/4	25.2 - 33.5	earthy
7/6	28.3 - [illegible]7.7	earthy
7/10	16.0 - 21.3	mild earthy
7/14	14.2 - 18.9	very mild earthy
7/17	8.0 - 10.7	earthy
7/21	10.7 - 14.2	--
Echo Bay Station 1		
3/21	5.44 - 6.22	algal odor
3/25	6.32 - 8.43	earthy
5/13	12.0 - 13.7	strong fish odor
5/26	9.47 - 12.7	sweet fishy
5/29	9.52 - 12.7	definite earthy-fishy
6/5	10.7 - 14.2	earthy-slight fishy
6/9	14.2 - 18.9	earthy-slight fishy
6/12	21.4 - 28.5	sweet fishy
6/16	7.1 - 9.53	weak, non-descriptive
6/19	7.1 - 9.47	earthy
6/23	14.2 - 18.9	--
6/25	10.7 - 14.2	sweet earthy
6/30	14.2 - 18.9	earthy-grassy
7/1	18.9 - 25.2	earthy
7/3	18.9 - 25.2	earthy
7/4	25.2 - 33.5	sweet earthy
7/6	21.3 - 28.3	earthy
7/10	14.2 - 18.9	mild earthy
7/14	10.7 - 14.2	earthy
7/17	10.7 - 14.2	--
7/21	9.47 - 12.7	--
Echo Bay Station 2		
3/25	4.74 - 5.43	earthy
5/13	9.3 - 10.64	fishy odor
5/26	7.05 - 9.47	sweet fishy
5/29	9.52 - 12.7	definite earthy
6/5	21.4 - 28.4	earthy-fishy
6/9	14.2 - 18.9	earthy-slight fishy
6/12	21.4 - 28.5	earthy-fishy
6/16	5.33 - 7.1	light, non-descriptive
6/19	9.47 - 12.7	earthy

Table 58 (continued)

Date	Threshold Odor Number Range	Odor Description
Echo Bay Station 2 (cont)		
6/23	9.45 - 12.6	--
6/25	10.7 - 14.2	earthy
6/30	14.2 - 18.9	earthy-grassy
7/1	14.2 - 18.9	--
7/3	18.9 - 25.2	earthy
7/4	25.2 - 33.5	slight earthy
7/6	21.3 - 28.3	earthy
7/10	14.2 - 18.9	--
7/14	10.7 - 14.2	earthy-grassy
7/17	10.7 - 14.2	--
7/21	8.0 - 10.7	--
Smith Bay Station 1		
4/22	2.37 - 2.7	slight earthy
5/13	4.06 - 4.64	almost sweet-fishy odor
5/26	5.33 - 7.1	earthy-fishy
5/29	10.7 - 14.2	very strong fish odor
6/5	18.9 - 25.2	heavy fish-earthy
6/9	28.4 - 38.0	strong earthy-fishy
6/16	5.33 - 7.1	light fishy odor
6/19		petrol odor
6/23	3.55 - 4.74	--
6/25	5.33 - 7.1	sweet
6/30	7.1 - 9.47	earthy
7/1	6.32 - 8.42	--
7/3	8.0 - 10.7	earthy
7/4	10.7 - 14.2	--
7/10	9.47 - 12.7	non-descriptive
7/14	7.1 - 9.47	very mild earthy
7/17	10.7 - 14.2	petrol odor
7/21	5.33 - 7.1	--
Smith Bay Station 2		
5/13	3.56 - 4.06	slight fish odor
5/26	5.33 - 7.1	sweet fishy
5/29	8.0 - 10.7	very strong fish odor
6/5	18.9 - 25.2	strong fish odor
6/9	28.4 - 38.0	strong fishy
6/16	7.1 - 9.53	earthy
6/19	9.47 - 12.7	sweet earthy

Table 58 (continued)

Date	Threshold Odor Number Range	Odor Description
Smith Bay Station 2 (cont)		
6/23	4.74 - 6.32	--
6/25	3.55 - 4.74	sweet earthy
6/30	6.32 - 8.1	non-descriptive
7/1	5.33 - 8.1	--
7/3	4.73 - 6.33	--
7/4	7.1 - 9.47	earthy
7/10	7.1 - 9.47	--
7/14	5.33 - 7.1	mild earthy
7/17	10.7 - 14.2	mild petrol
7/21	5.33 - 7.1	--
Smith Bay Tap Water		
4/22	1.49 - 1.69	
5/13	1.0 - 1.14	
5/26	4.0 - 5.33	
5/29	21.2 - 28.3	
6/5	18.9 - 25.2	
6/9	10.7 - 14.2	
6/16	5.33 - 7.1	
6/19	5.33 - 7.1	
6/23	3.55 - 4.74	
6/25	5.33 - 7.1	
6/30	5.33 - 7.1	
7/1	3.55 - 4.73	
7/3	5.33 - 7.1	
7/4	5.33 - 7.1	
7/10	3.55 - 4.73	
7/14	3.55 - 4.73	
7/17	4.0 - 5.33	
7/21	2.67 - 3.55	

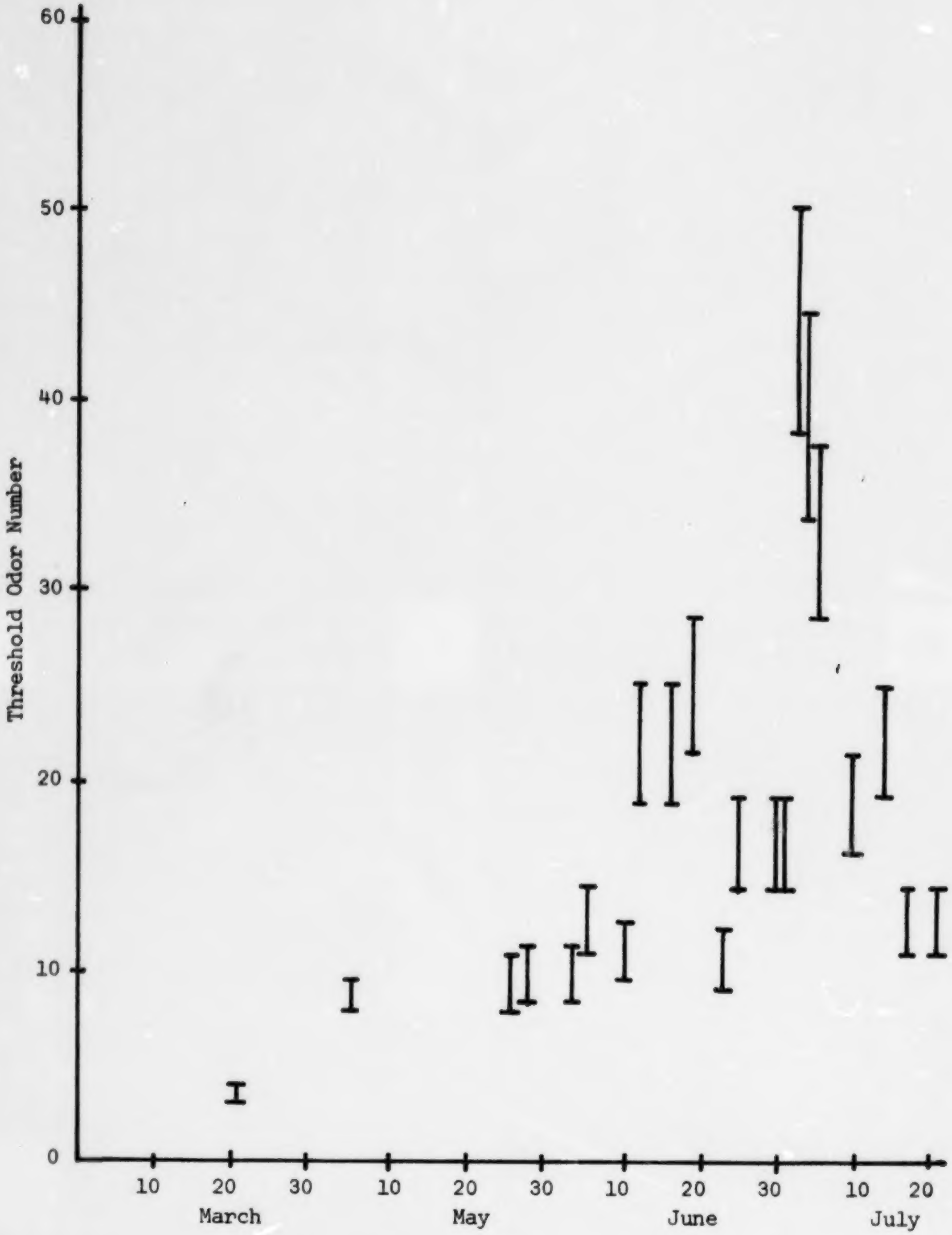


Figure 58 - Threshold Odor Number
Dunham Bay Station No. 1

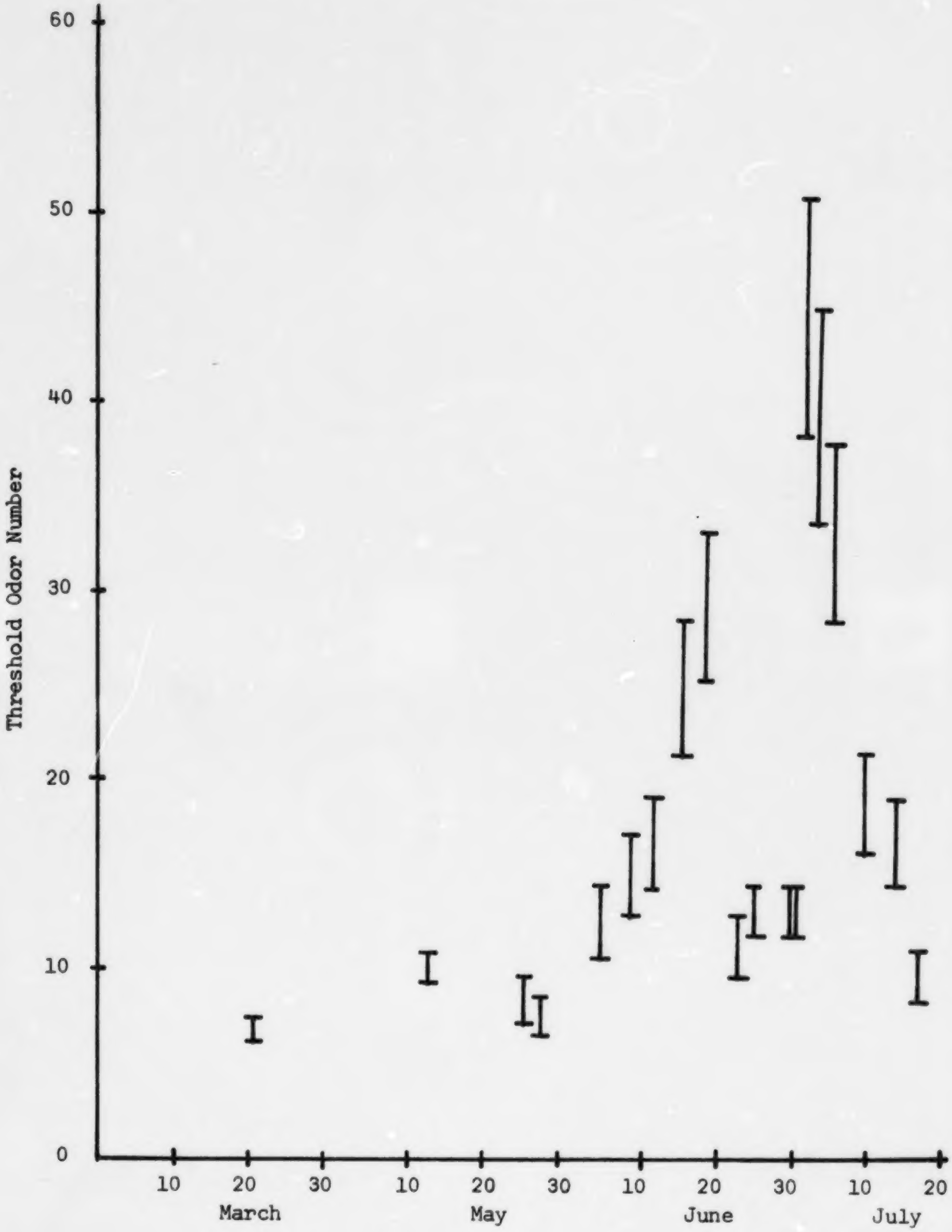


Figure 59 - Threshold Odor Number
Dunham Bay Station No. 3

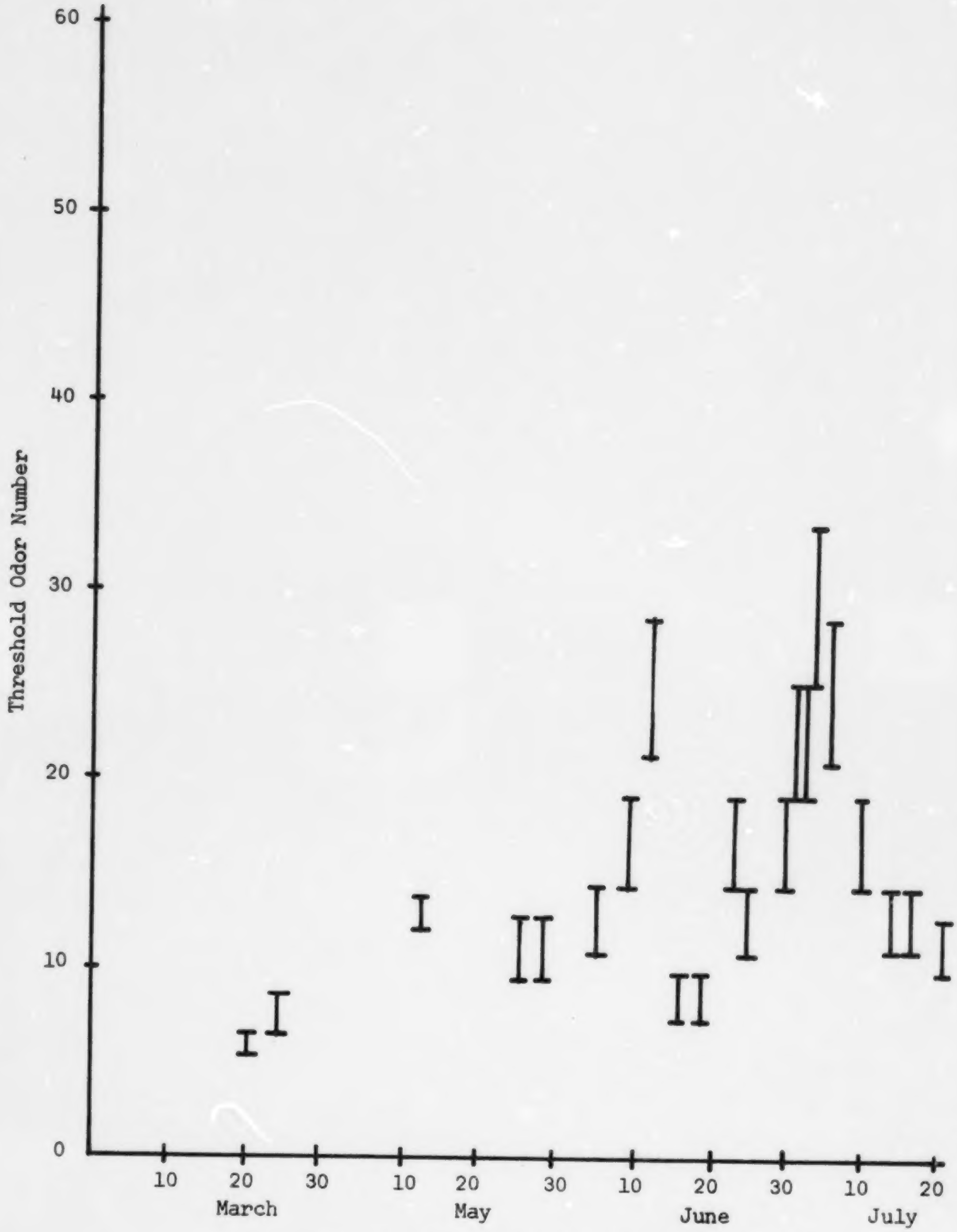


Figure 60 - Threshold Odor Number
Echo Bay Station No. 1

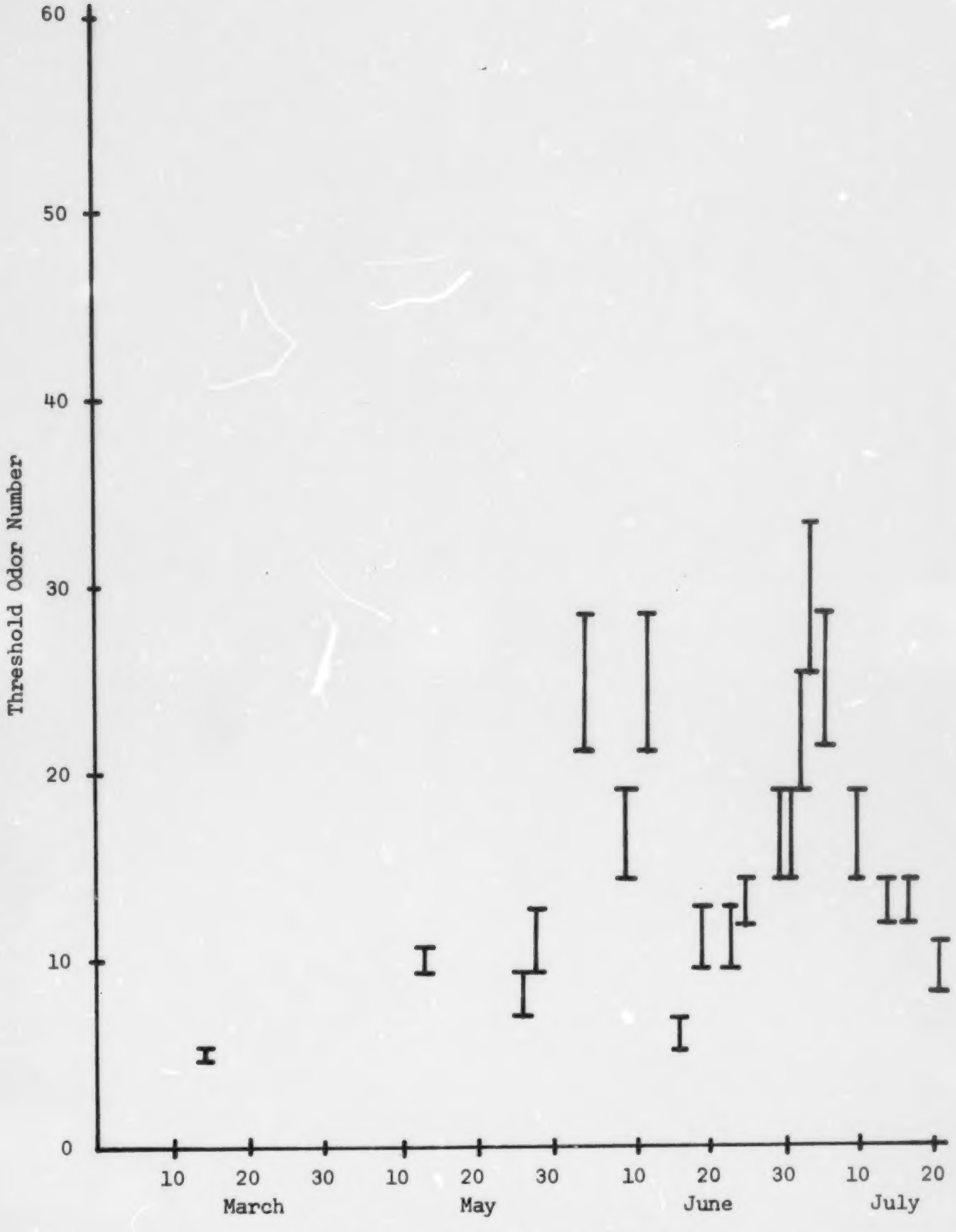


Figure 61 - Threshold Odor Number
Echo Bay Station No. 2

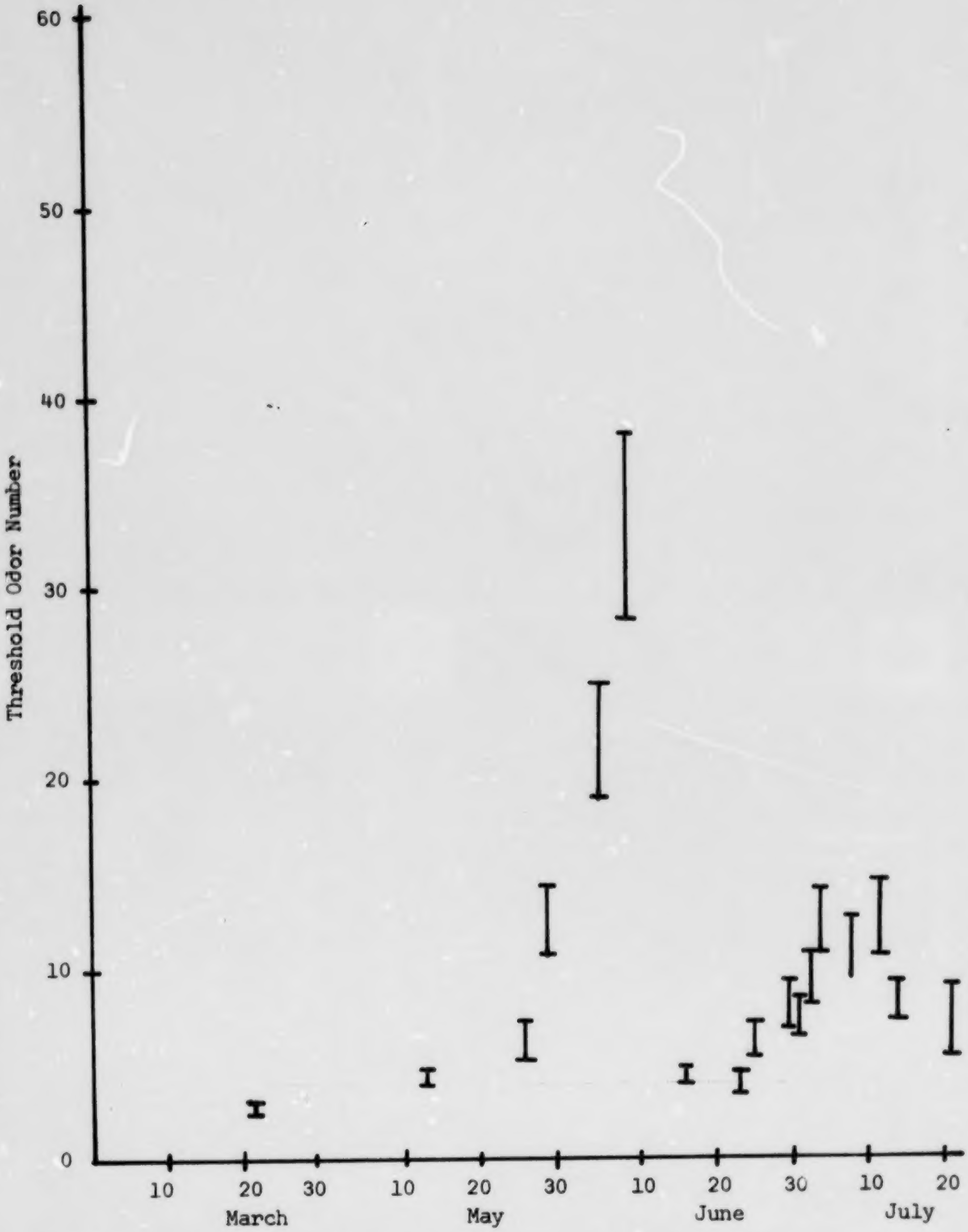


Figure 62 - Threshold Odor Number
Smith Bay Station No. 1

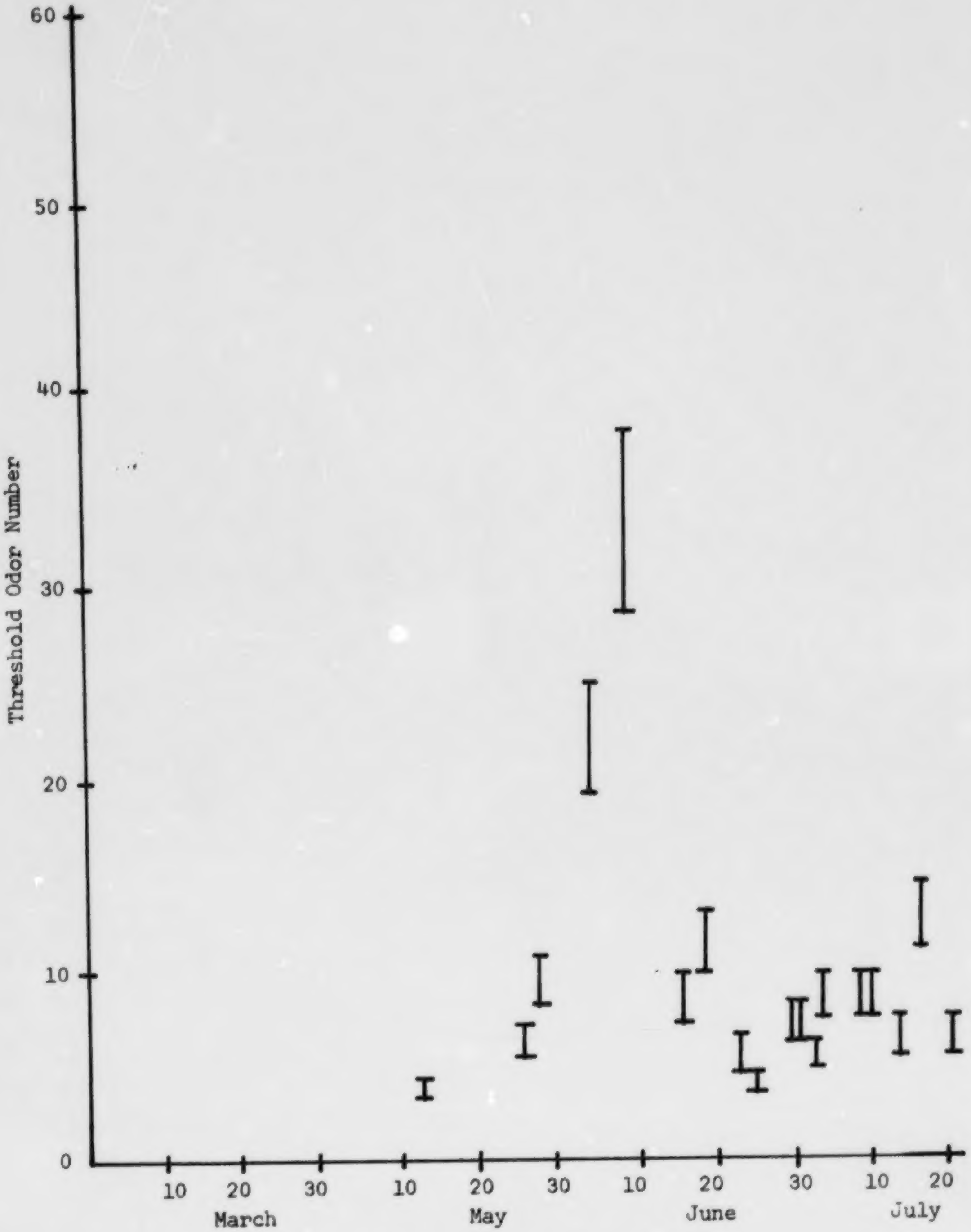


Figure 63 - Threshold Odor Number
Smith Bay Station No. 2

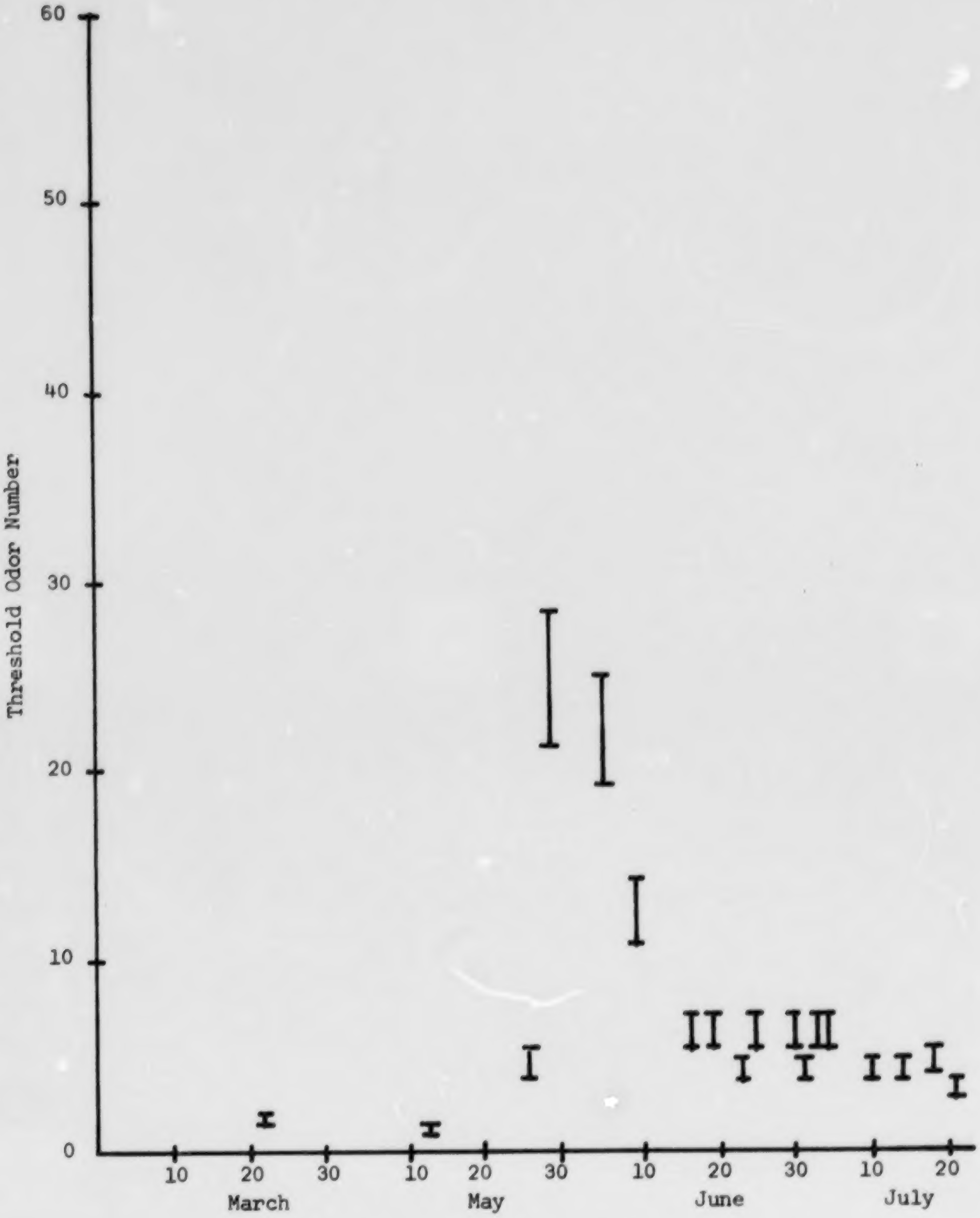


Figure 64 - Threshold Odor Number
Smith Bay Tap Water

It can be seen from the data plots that a sharp rise in threshold odor numbers occurred in samples from Dunham Bay and Echo Bay following the Memorial Day weekend and the Fourth of July weekend. These odors were described as being strongly fishy. After each rise, the values rather promptly returned to lower values. These weekends corresponded to unusually heavy boat usage and were characterized by weather ideal for boating. The stations in Smith Bay showed a rise following the Memorial Day weekend but no appreciable rise over the Fourth of July weekend.

It was noted that a number of the higher threshold numbers were associated with the presence of certain algae, such as Dinobryon, which are known to produce strong fish-like odors, as indicated by the examination of samples taken at the same time that samples were taken for odor examination.

DISCUSSION

Stewart and Howard have reported that waters having threshold odor numbers greater than three are usually considered objectionable by most people (77). Other investigators have reported somewhat higher values for water considered potable in other respects. In any event, this would indicate that Lake George waters at the stations used frequently had threshold odor numbers considerably in excess of values held desirable.

The tests conducted in the test tank were primarily for the purpose of collecting exhaust products and water saturated with exhaust products for use in other parts of the total investigation. Under these severe conditions the levels of odor numbers were not typical of lake conditions. They were helpful, however, in that they indicated the type and intensity of petrol odor generated by engines under heavy usage. They also were useful in confirming previous work on the effect of operating parameters on the quantity of exhaust products discharged (3).

The results of the investigation on the effects of aging of samples on the level and nature of odors is highly suggestive. The decrease in odor numbers for samples exposed to the air may have been due in part to the loss from evaporation, as indicated in another part of this study. A few bacterial culture tests, however, suggest that bacterial action may also have been a contributing cause to the decrease in odor and disappearance of the petrol odor.

It may be noted that the odors reported in the lake studies were usually described as earthy or fishy and occasionally as petrol-like. In a study on the pollutional effects of outboard motor exhaust, English et al. (22) noted that the majority of odors reported for bodies of water in which outboard engines had been run were designated as "earthy". According to Baylis (4), microscopic organisms probably are responsible for more tastes and odors than any other cause.

The results suggest that the odors in the water are at least in part related to the presence of algae and/or other microbiologic organisms. It is also suggested that a relationship exists between odor levels and the degree of boat usage in the vicinity where sampling occurred. In the bays where boat usage was high, as in Dunham Bay, and to a lesser extent in Echo Bay, the threshold odor numbers were considerably higher than the numbers in Smith Bay where boat usage was much less. In addition, the peaks in odor numbers followed with a slight delay the periods of heaviest boat usage.

While the threshold odor test is a subjective test, it has been an extremely useful indicator of changes in the concentration of odor producers. With experienced personnel the results are highly reproducible and sensitive.

SECTION XI - EVAPORATION STUDIES

It has frequently been observed that a major part of the exhaust products from outboard engines discharged to water bodies, accumulates on the water surface in thin films. Since a relatively large surface area per unit weight of exhaust products is thus exposed to the air, it is reasonable to expect that evaporation of the low-boiling fractions of the exhaust products would be significant. In order to examine the role of evaporation on the equilibrium concentrations of liquid exhaust products found in a lake environment, laboratory studies of the rates of evaporation were made.

PROCEDURE

Initial tests were made by adding measured quantities of exhaust products to water, equilibrating with an air flow at a known temperature in a water bath, extracting the residual material with a solvent, and evaporating off the solvent. It was found, however, that because the exhaust products contain a fraction of low boilers, this method gave high results because of the loss of the low boiling fraction. It was also found that a portion of the water also evaporated, introducing a second type of error. Consequently, the results using this method have not been included.

The method that was established for use involved measuring a weighed amount of exhaust products into a flask which was attached to a rotary evaporator operating in a water bath held at a desired temperature. A measured air stream was introduced into the flask to carry off evaporated products above the liquid. At measured intervals the flask was removed and weighed to obtain the loss due to evaporation. The apparatus used is shown schematically in Fig. 65.

Tests were made on the products collected from a 33 horsepower Evinrude engine operated at 1200 RPM in a test tank. For comparative purposes, tests were also made on straight Mobil regular gasoline, and on straight Mobil outboard engine oil. Tests were also made on a 50 to 1 mixture of gasoline and oil as used for engine fuel. Rates of evaporation were established at temperatures of 5°C, 10°C, 15°C, 20°C, 25°C, and 30°C for all materials tested except the oil which had a very low evaporation rate.

RESULTS

The results of the evaporation tests have been summarized in Tables 59-62 and plotted in Figs. 66-79. The evaporation rates have been expressed in several ways. To demonstrate the proportion of total exhaust products which evaporate as a function of time, the rate has been expressed as a percent evaporation. In addition, since the quantity of

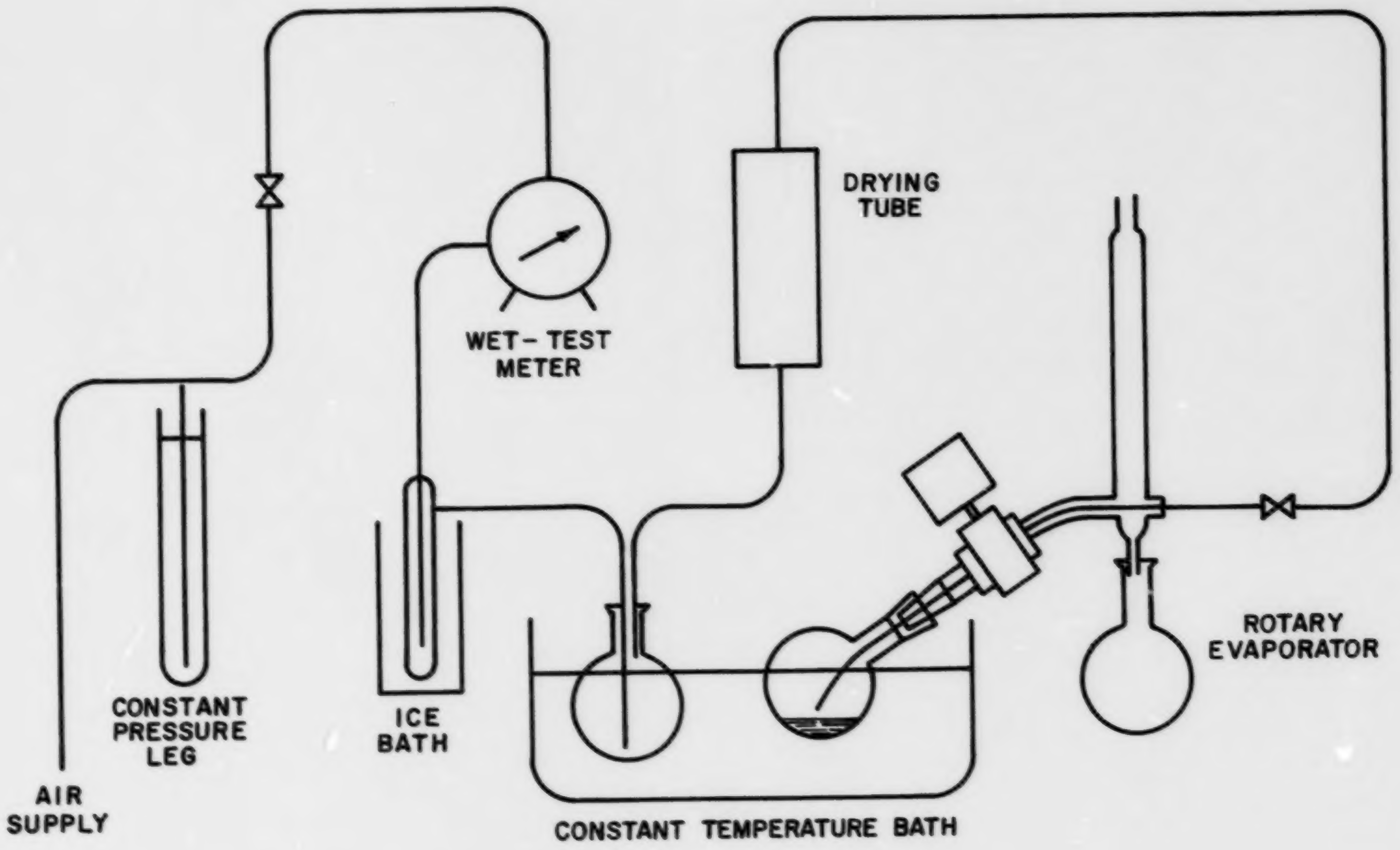

AIR SUPPLY
CONSTANT PRESSURE LEG
ICE BATH
WET- TEST METER
DRYING TUBE
CONSTANT TEMPERATURE BATH
ROTARY EVAPORATOR

Figure 65 - Evaporation Test Apparatus

Table 59

Evaporation Studies

Mobil Gasoline

Temperature °C	Cumulative Air Flow S.C.F.	Cumulative Time Hours	Cumulative Percent Evaporation	Cumulative Evap. Rate Gms/Hr	Cumulative Evap. Flux Gms/Hr/Gm Sample
5	0.047	0.020	9.12	11.36	4.56
5	0.140	0.060	20.33	8.44	3.39
5	0.326	0.141	31.18	5.51	2.21
5	0.792	0.326	44.18	3.38	1.36
5	1.724	0.745	56.14	1.88	0.75
5	2.656	1.148	63.06	1.37	0.55
5	0.047	0.022	10.79	11.57	4.91
5	0.140	0.066	21.04	7.52	3.19
5	0.326	0.300	41.15	3.23	1.37
5	0.792	0.518	49.47	2.25	0.95
5	1.724	0.954	58.80	1.18	0.50
5	2.656	1.389	64.60	1.09	0.41
10	0.046	0.021	15.51	17.62	7.39
10	0.138	0.062	22.61	8.70	3.65
10	0.322	0.143	34.58	5.77	2.42
10	0.783	0.347	48.50	3.33	1.40
10	1.705	0.759	63.38	1.91	0.80
10	2.627	1.171	67.74	1.38	0.58

Table 59 (continued)

Temperature °C	Cumulative Air Flow S.C.F.	Cumulative Time Hours	Cumulative Percent Evaporation	Cumulative Evap. Rate Gms/Hr	Cumulative Evap. Flux Gms/Hr/Gm Sample
10	0.046	0.022	8.04	8.85	3.65
10	0.139	0.065	16.97	6.32	2.61
10	0.325	0.150	26.94	4.35	1.80
10	0.791	0.364	39.19	2.61	1.08
10	1.769	0.811	51.28	1.53	0.63
10	2.701	1.495	59.62	0.97	0.40
15	0.047	0.020	12.18	15.04	6.09
15	0.140	0.061	25.28	10.24	4.14
15	0.326	0.142	38.00	6.61	2.67
15	0.792	0.346	52.88	3.78	1.53
15	1.724	0.755	65.66	2.15	0.87
15	1.724	1.245	73.22	1.45	0.59
15	0.046	0.021	14.80	17.48	7.08
15	0.139	0.063	28.64	11.23	4.55
15	0.324	0.146	40.72	6.89	2.79
15	0.787	0.355	54.53	3.79	1.53
15	1.712	0.775	66.96	2.13	0.86
15	2.637	1.197	73.97	1.53	0.62
20	0.047	0.021	14.75	18.62	7.03
20	0.139	0.062	28.62	12.23	4.62
20	0.324	0.145	41.77	7.63	2.88
20	0.790	0.351	56.71	4.27	1.61
20	1.722	0.847	71.16	2.22	0.84
20	2.654	1.179	76.26	1.71	0.65

Table 59 (continued)

Temperature °C	Cumulative Air Flow S.C.F.	Cumulative Time Hours	Cumulative Percent Evaporation	Cumulative Evap. Rate Gms/Hr	Cumulative Evap. Flux Gms/Hr/Gm Sample
20	0.047	0.018	12.52	17.27	6.95
20	0.141	0.057	25.75	11.22	4.52
20	0.329	0.135	38.53	7.09	2.85
20	0.800	0.333	52.90	3.95	1.59
20	1.742	0.727	65.65	2.24	0.90
20	2.684	1.120	72.39	1.61	0.65
25	0.046	0.021	17.60	19.36	8.38
25	0.139	0.062	33.13	12.34	5.34
25	0.324	0.164	49.19	6.93	3.00
25	0.787	0.370	63.36	3.95	1.71
25	1.712	0.783	75.99	2.24	0.97
25	2.637	1.198	82.20	1.58	0.68
30	0.046	0.021	24.20	29.31	11.53
30	0.137	0.062	40.46	16.59	6.52
30	0.319	0.146	54.77	9.54	3.75
30	0.784	0.357	70.15	5.00	1.97
30	1.694	0.783	82.20	2.67	1.05
30	2.604	1.215	88.37	1.85	0.73

Table 60

Evaporation Studies

Exhaust Products from 33 H.P. Evinrude @ 1200 RPM

Temperature ^{o}C	Cumulative Air Flow S.C.F.	Cumulative Time Hours	Cumulative Percent Evaporation	Cumulative Evap. Rate Gms/Hr	Cumulative Evap. Flux Gms/Hr/Gm Sample
5	0.046	0.027	1.11	0.340	0.412
5	0.138	0.080	4.61	0.475	0.576
5	0.322	0.186	8.52	0.378	0.458
5	0.782	0.449	14.48	0.267	0.324
5	1.702	0.972	23.10	0.196	0.237
5	2.622	1.495	28.34	0.156	0.189
10	0.046	0.026	1.85	0.587	0.712
10	0.138	0.079	5.17	0.540	0.655
10	0.322	0.183	9.86	0.444	0.538
10	0.780	0.446	17.17	0.318	0.386
10	1.696	0.973	26.00	0.220	0.267
10	2.612	1.495	32.28	0.178	0.216
15	0.046	0.025	2.54	0.840	1.017
15	0.137	0.075	7.00	0.772	0.935
15	0.320	0.175	12.71	0.600	0.727
15	0.780	0.425	20.75	0.403	0.488
15	1.693	0.925	31.10	0.277	0.355
15	2.606	1.425	37.98	0.220	0.266

Table 60 (continued)

Temperature °C	Cumulative Air Flow S.C.F.	Cumulative Time Hours	Cumulative Percent Evaporation	Cumulative Evap. Rate Gms/Hr	Cumulative Evap. Flux Gms/Hr/Gm Sample
20	0.046	0.028	3.87	1.134	1.380
20	0.137	0.080	8.71	0.895	1.089
20	0.320	0.186	15.17	0.670	0.815
20	0.780	0.441	25.25	0.470	0.572
20	1.693	0.985	36.98	0.308	0.375
20	2.606	1.518	44.61	0.241	0.293
25	0.045	0.026	5.22	1.586	1.938
25	0.136	0.076	11.46	1.235	1.509
25	0.318	0.177	19.32	0.893	1.091
25	0.775	0.431	31.31	0.593	0.724
25	1.688	0.940	45.14	0.393	0.480
25	2.601	1.480	53.06	0.294	0.359
30	0.046	0.026	6.44	2.041	2.477
30	0.137	0.076	13.80	1.500	1.820
30	0.320	0.177	23.22	1.081	1.312
30	0.780	0.431	37.33	0.714	0.867
30	1.693	0.938	52.18	0.458	0.556
30	2.606	1.440	59.50	0.340	0.413

Table 61

Evaporation Studies

Gasoline Plus Oil - 50:1 Mix

Temperature °C	Cumulative Air Flow S.C.F.	Cumulative Time Hours	Cumulative Percent Evaporation	Cumulative Evap. Rate Gms/Hr	Cumulative Evap. Flux Gms/Hr/Gm Sample
5	0.047	0.021	9.14	12.00	4.35
5	0.141	0.063	20.18	8.83	3.20
5	0.329	0.148	30.83	5.74	2.08
5	0.800	0.362	43.26	3.29	1.19
5	1.741	0.792	55.83	1.94	0.70
5	2.682	1.227	62.73	1.40	0.51
10	0.047	0.0219	8.23	9.65	3.76
10	0.141	0.0662	17.87	6.94	2.70
10	0.329	0.1552	29.04	4.81	1.87
10	0.800	0.3775	42.36	2.88	1.12
10	1.741	0.8221	54.86	1.71	0.67
10	2.682	1.2662	61.96	1.26	0.49
15	0.047	0.0199	11.49	16.58	5.77
15	0.140	0.0605	24.58	11.66	4.06
15	0.326	0.1419	36.39	7.36	2.56
15	0.792	0.3461	50.46	4.19	1.45
15	1.724	0.7586	63.30	2.39	0.83
15	2.656	1.1765	70.35	1.72	0.60

Table 61 (continued)

Temperature °C	Cumulative Air Flow S.C.F.	Cumulative Time Hours	Cumulative Percent Evaporation	Cumulative Evap. Rate Gms/Hr	Cumulative Evap. Flux Gms/Hr/Gm Sample
20	0.047	0.021	13.84	17.57	6.59
20	0.140	0.057	27.49	12.85	4.82
20	0.326	0.142	40.07	7.52	2.82
20	0.792	0.347	54.66	4.19	1.57
20	1.724	0.753	67.07	2.37	0.89
20	2.656	1.160	73.37	1.69	0.63
25	0.047	0.020	16.41	20.40	8.28
25	0.140	0.061	30.58	12.40	5.05
25	0.326	0.141	44.03	7.69	3.12
25	0.792	0.344	59.28	4.24	1.72
25	1.724	0.733	72.63	2.44	0.99
25	2.656	1.156	77.99	1.66	0.67
30	0.046	0.020	17.40	22.27	8.78
30	0.139	0.060	33.01	13.97	5.51
30	0.324	0.141	47.49	8.54	3.37
30	0.787	0.344	63.78	6.38	1.85
30	1.712	0.754	77.72	2.62	1.03
30	2.637	1.168	84.47	1.83	0.72

Table 62

Evaporation Studies

Mobil Outboard Super Oil - SAE 40

Temperature °C	Cumulative Air Flow S.C.F.	Cumulative Time Hours	Cumulative Percent Evaporation	Cumulative Evap. Rate Gms/Hr	Cumulative Evap. Flux Gms/Hr/Gm Sample
30	0.046	0.023	0.123	0.042	0.050
30	0.138	0.068	0.081	0.010	0.012
30	0.322	0.159	0.104	0.005	0.006
30	0.781	0.387	0.112	0.002	0.002
30	1.699	0.843	0.091	0.001	0.001
30	2.802	1.390	0.011	---	---
30	0.046	0.023	0.049	0.018	0.022
30	0.138	0.068	0.148	0.018	0.022
30	0.322	0.160	0.043	0.002	0.002
30	0.781	0.389	0.137	0.003	0.004
30	1.700	0.847	0.209	0.002	0.002
30	2.619	1.259	0.097	---	---
25	0.046	0.023	0.060	0.021	0.026
25	0.138	0.069	0.107	0.013	0.015
25	0.322	---	0.015	---	---
25	0.783	0.391	0.004	---	---
25	1.705	0.854	0.122	0.001	0.001
25	2.627	1.320	0.223	0.001	0.001

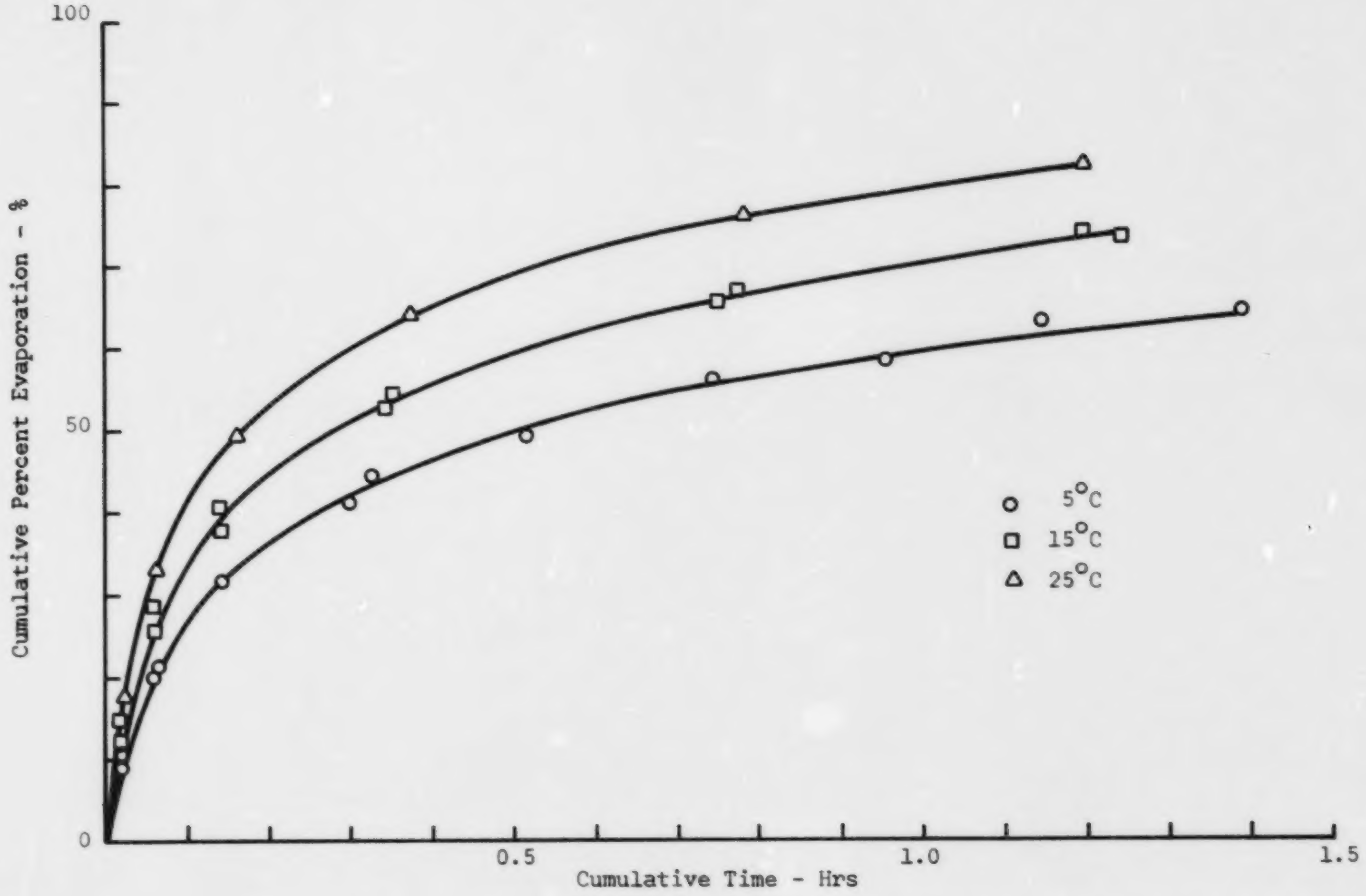


Figure 66 - Cumulative Percent Evaporation - Gasoline

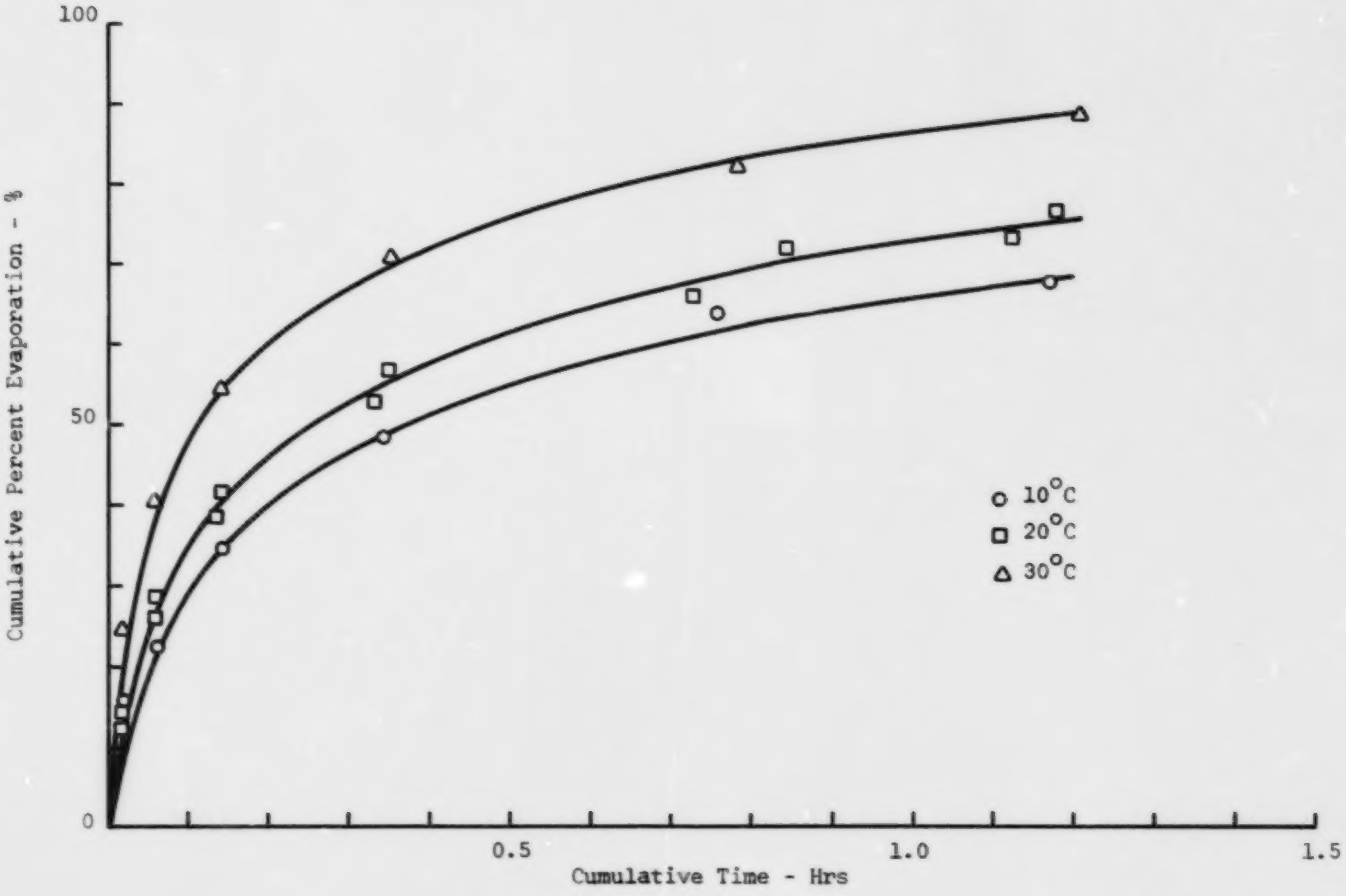


Figure 67 - Cumulative Percent Evaporation - Gasoline

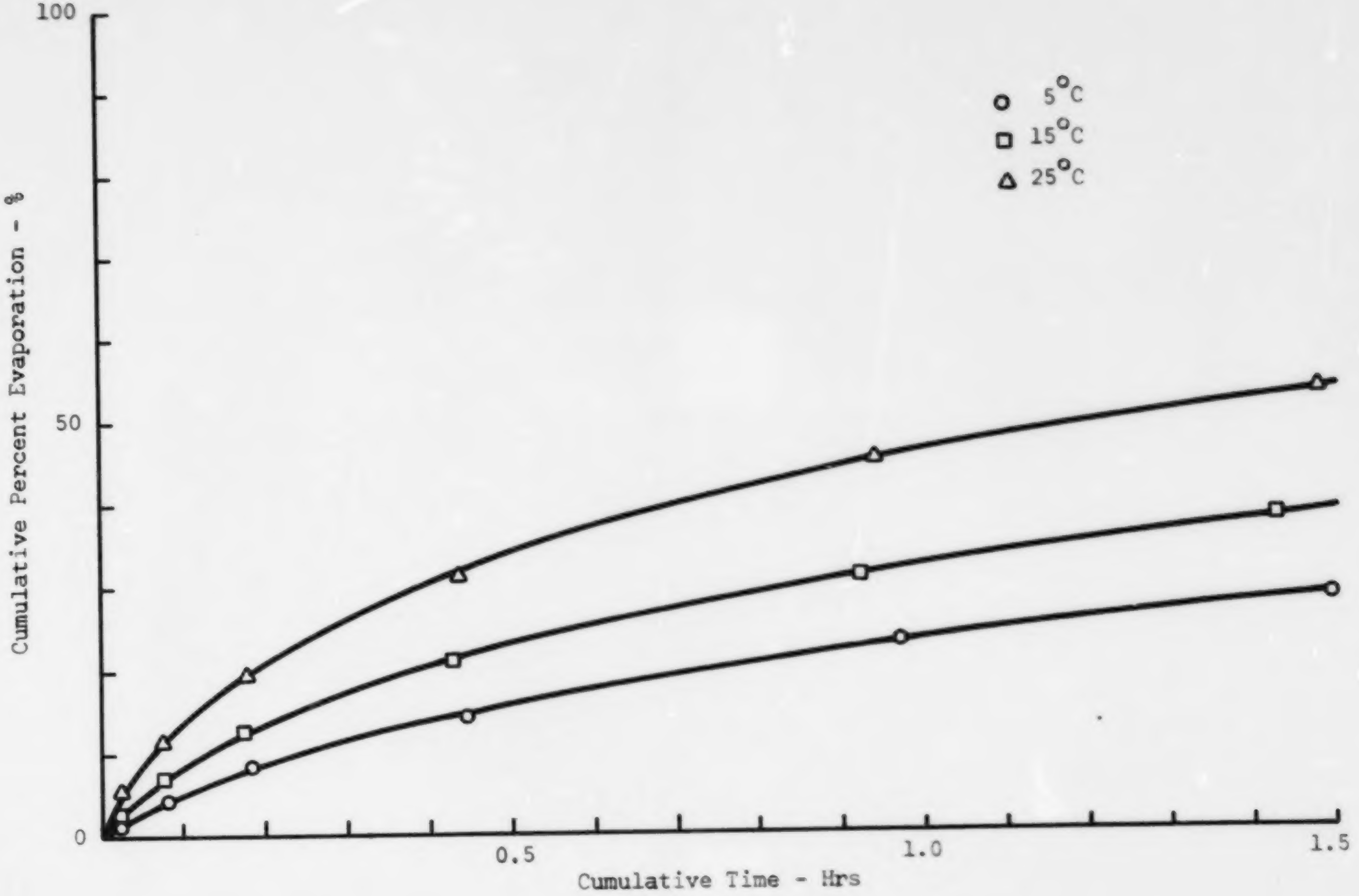


Figure 68 - Cumulative Percent Evaporation - Exhaust Products

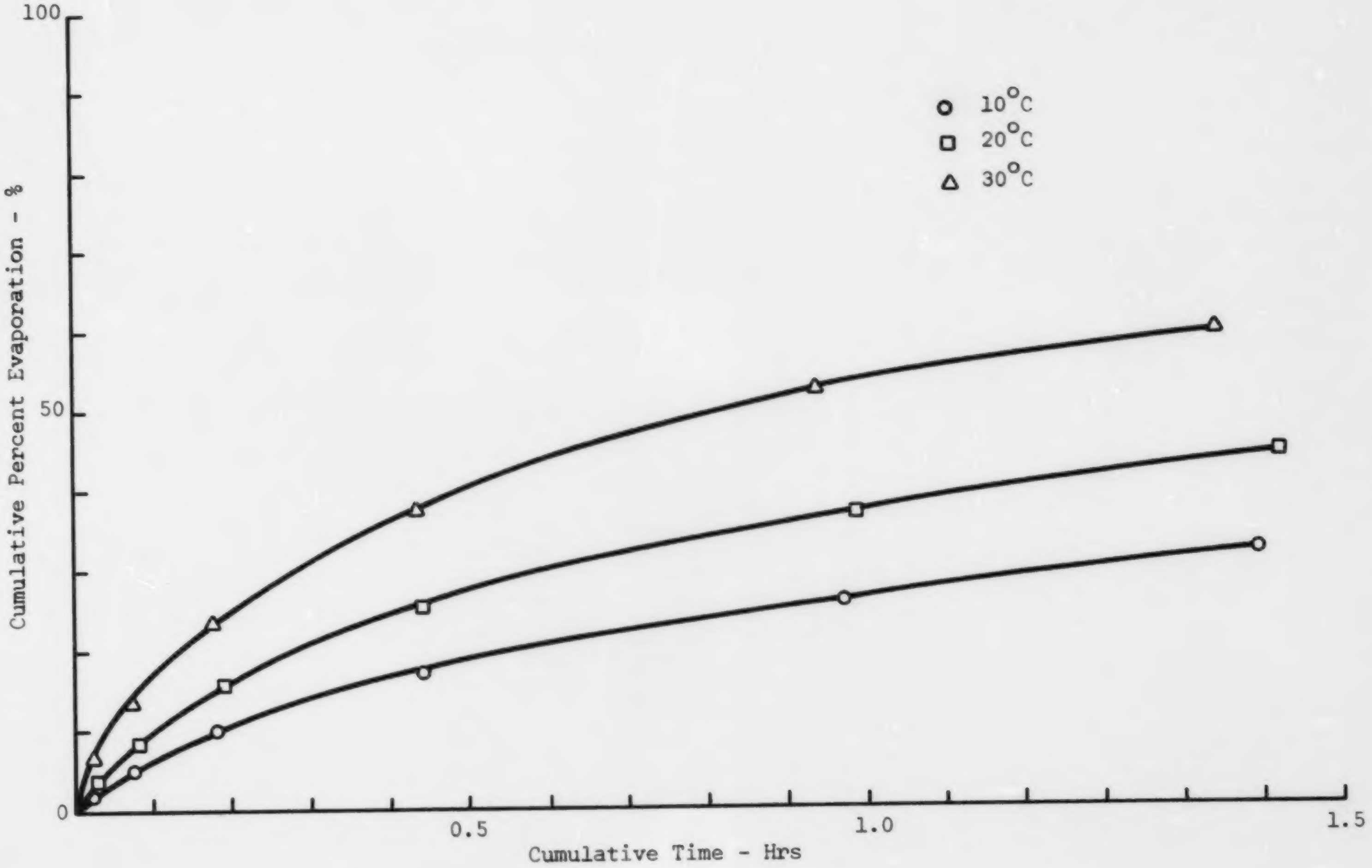


Figure 69 - Cumulative Percent Evaporation - Exhaust Products

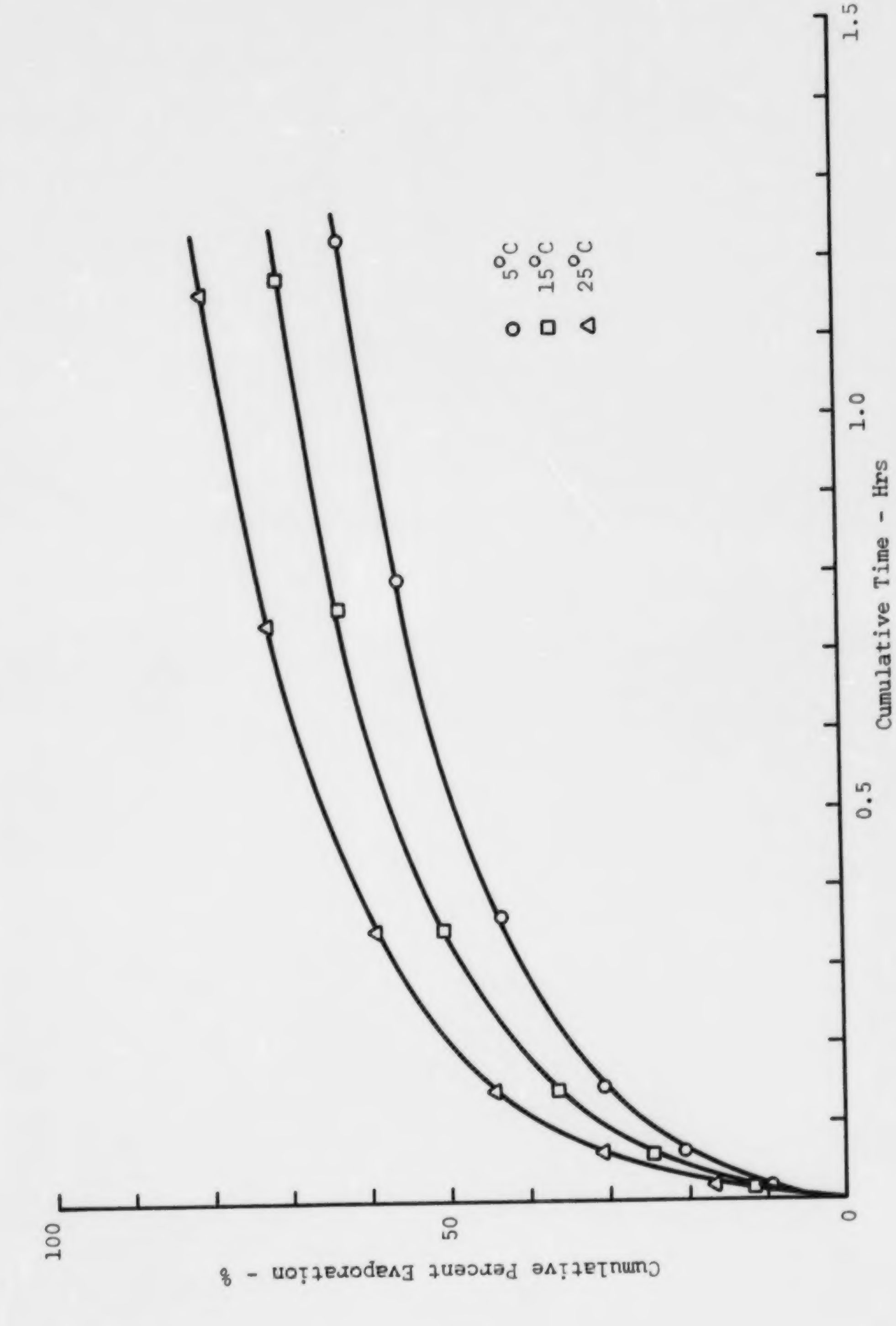


Figure 70 - Cumulative Percent Evaporation - Gasoline plus Oil

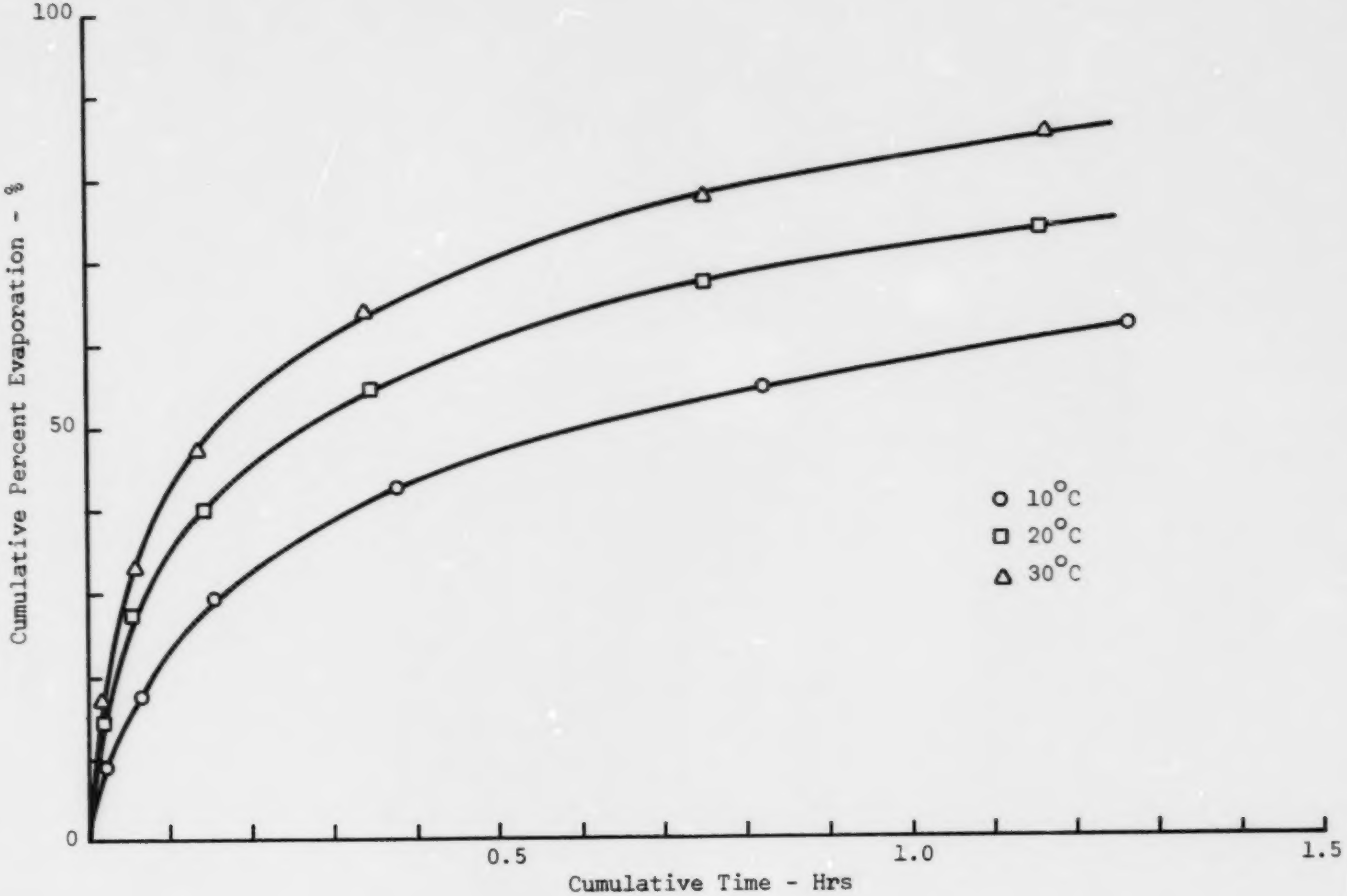


Figure 71 - Cumulative Percent Evaporation - Gasoline plus Oil

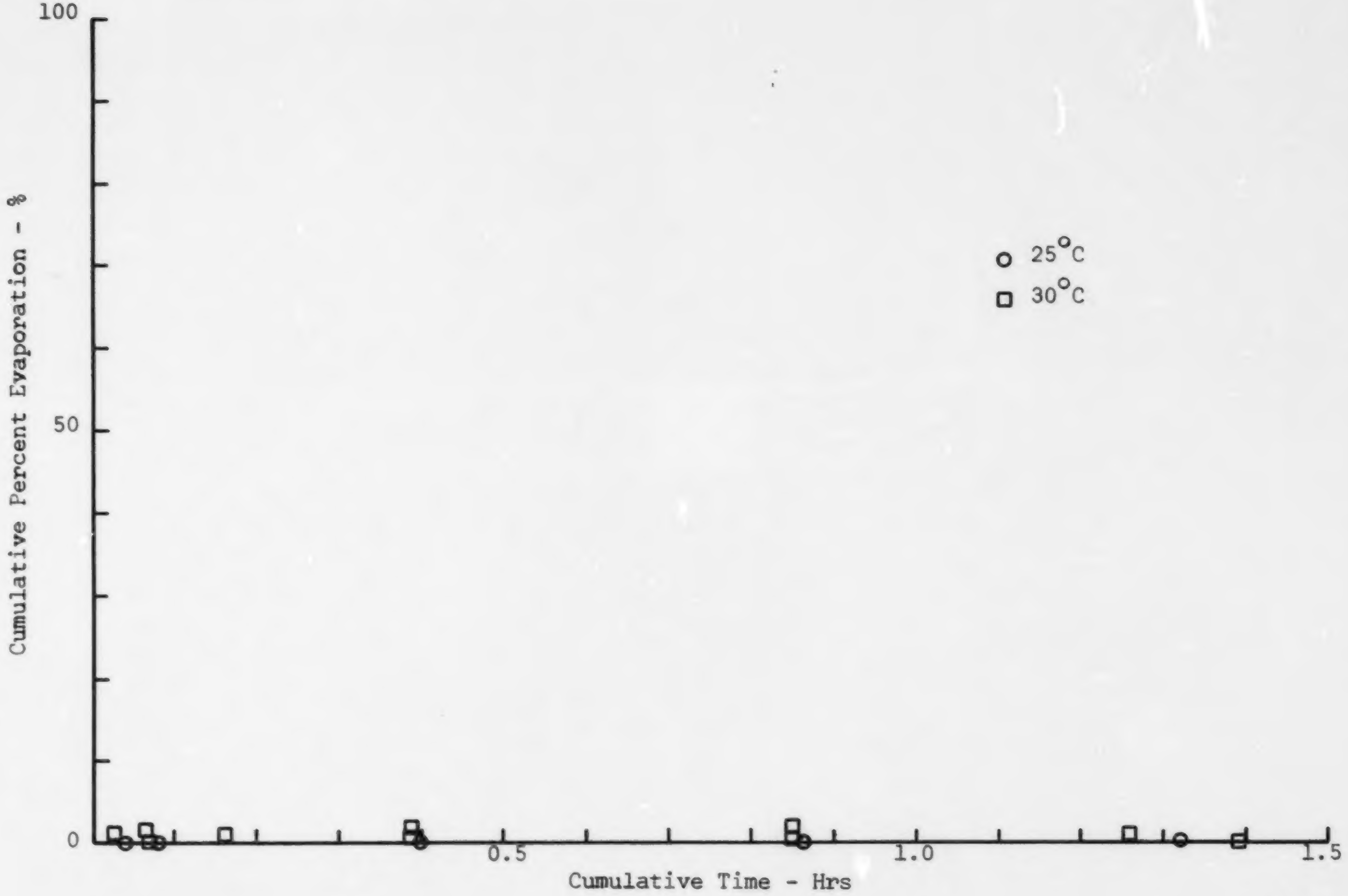


Figure 72 - Cumulative Percent Evaporation - Straight Oil

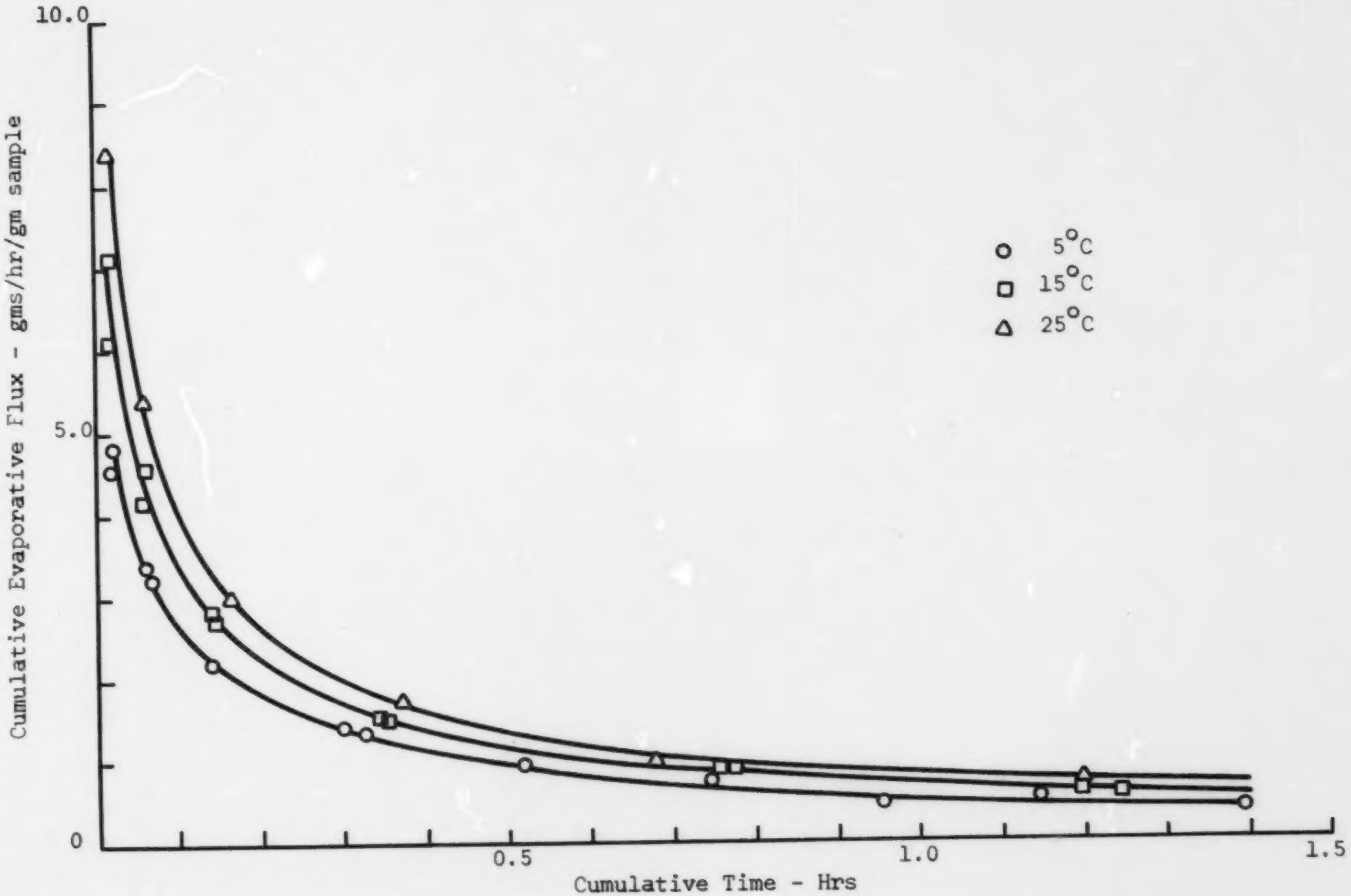


Figure 73 - Cumulative Evaporative Flux - Gasoline

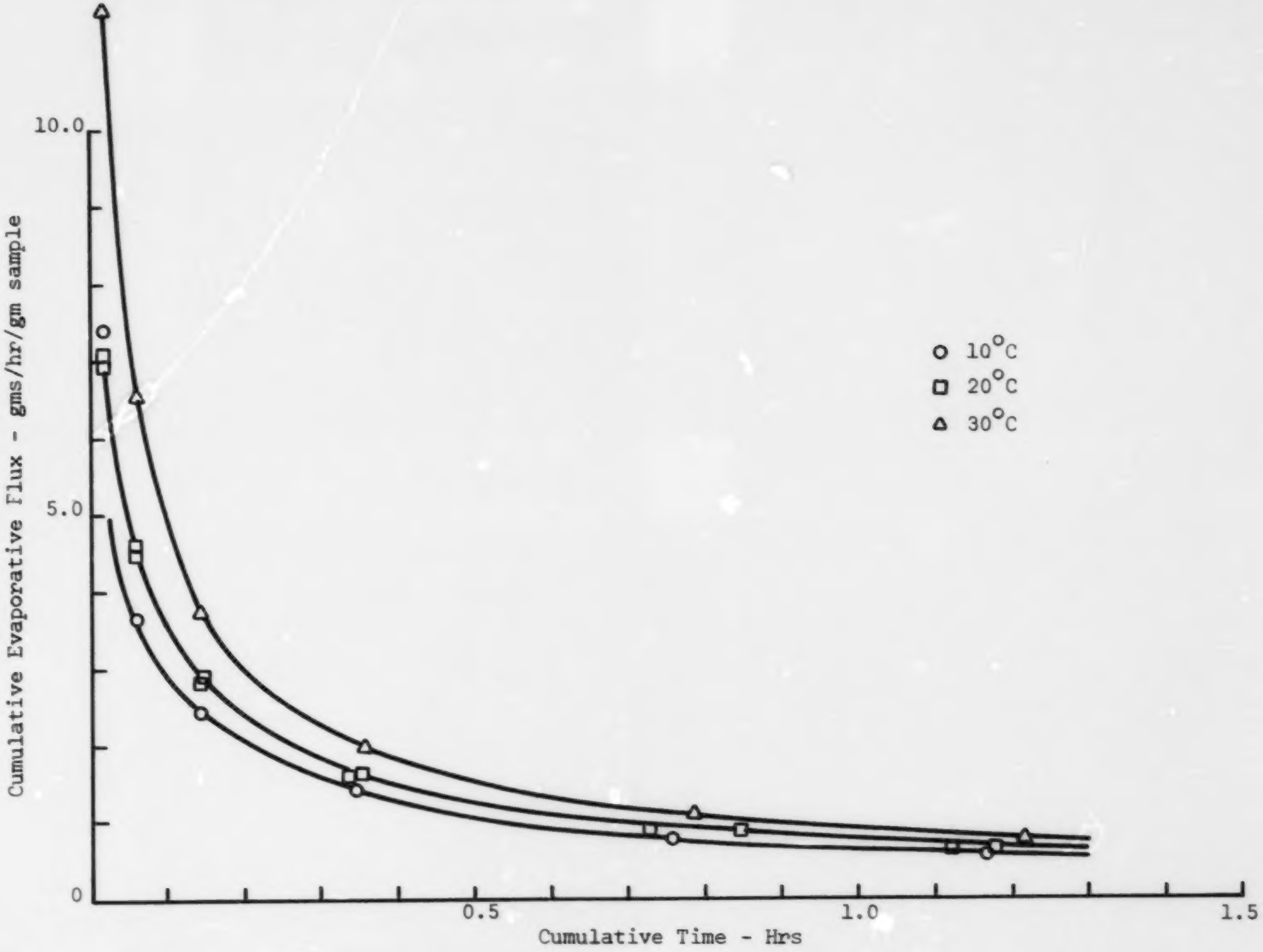


Figure 74 - Cumulative Evaporative Flux - Gasoline

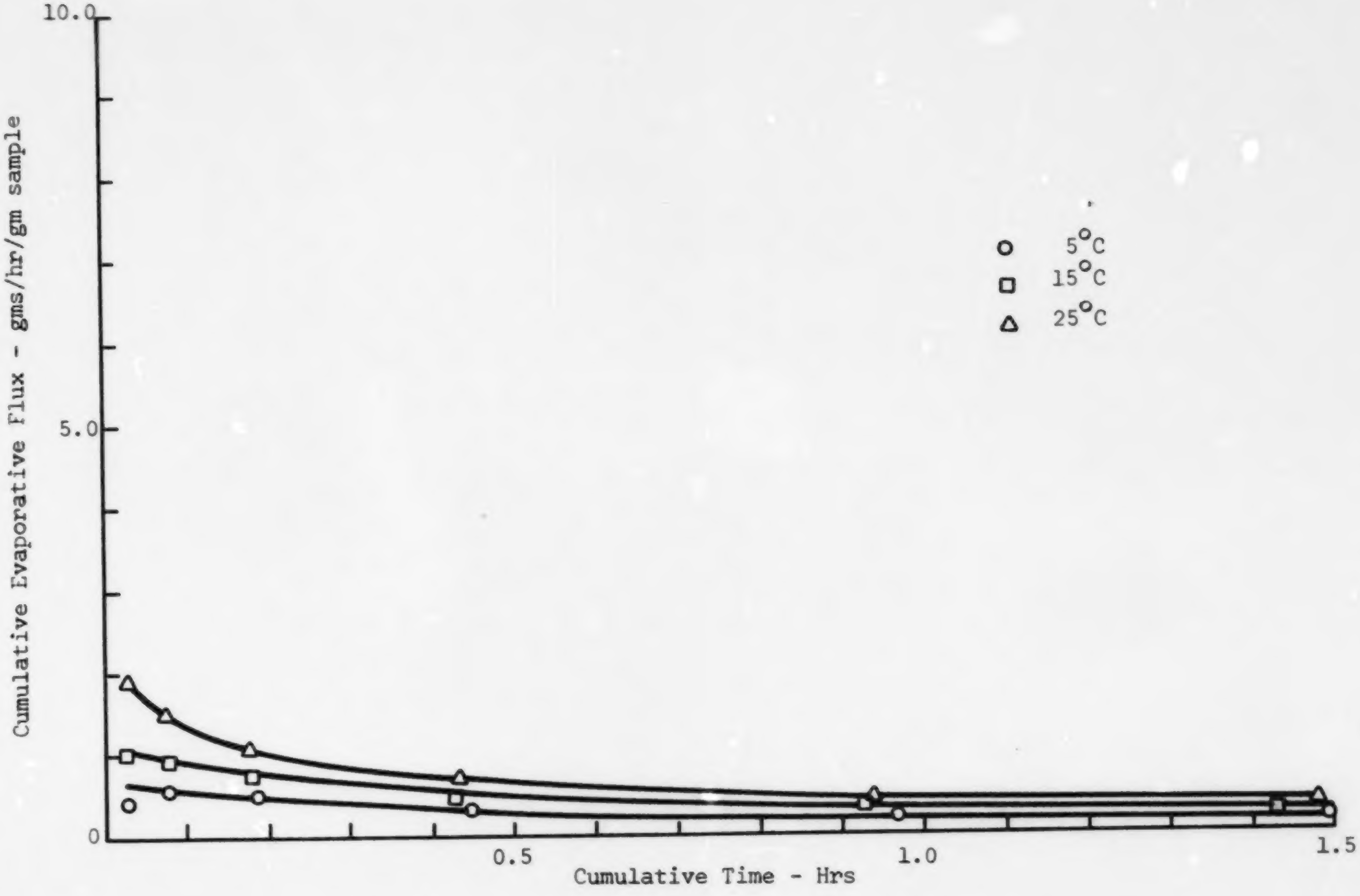


Figure 75 - Cumulative Evaporative Flux - Exhaust Products

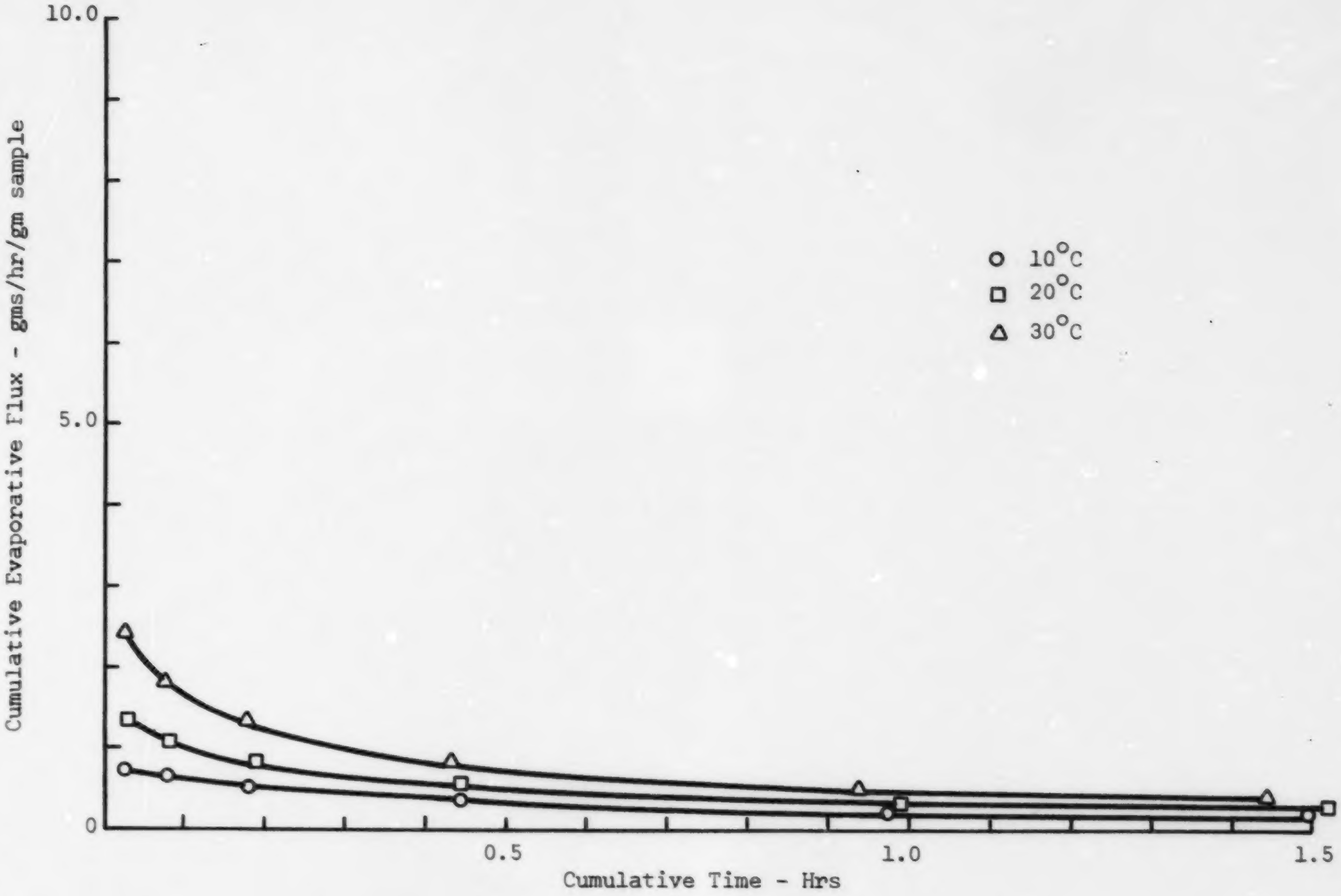


Figure 76 - Cumulative Evaporative Flux - Exhaust Products

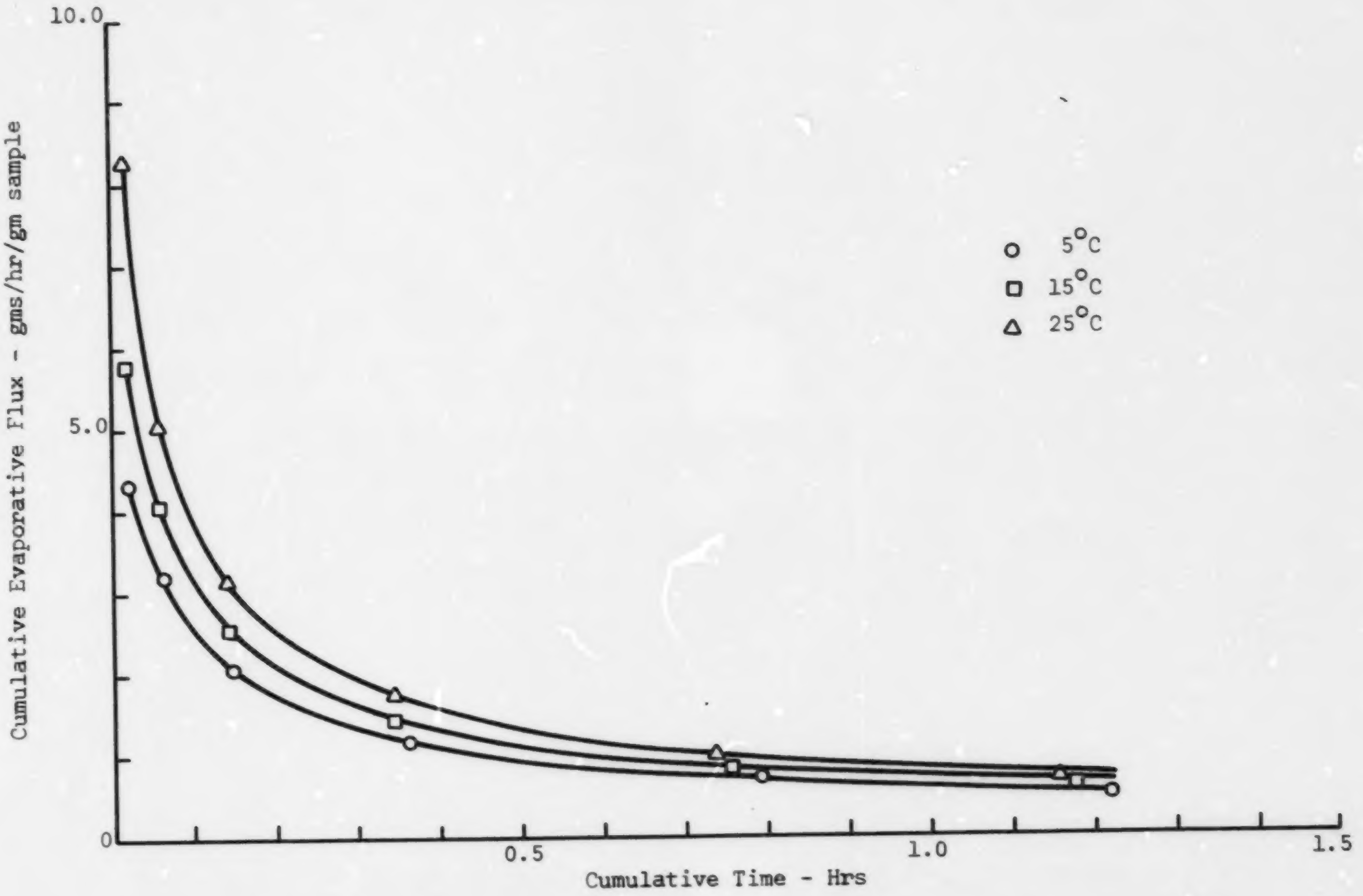


Figure 77 - Cumulative Evaporative Flux - Gasoline plus Oil

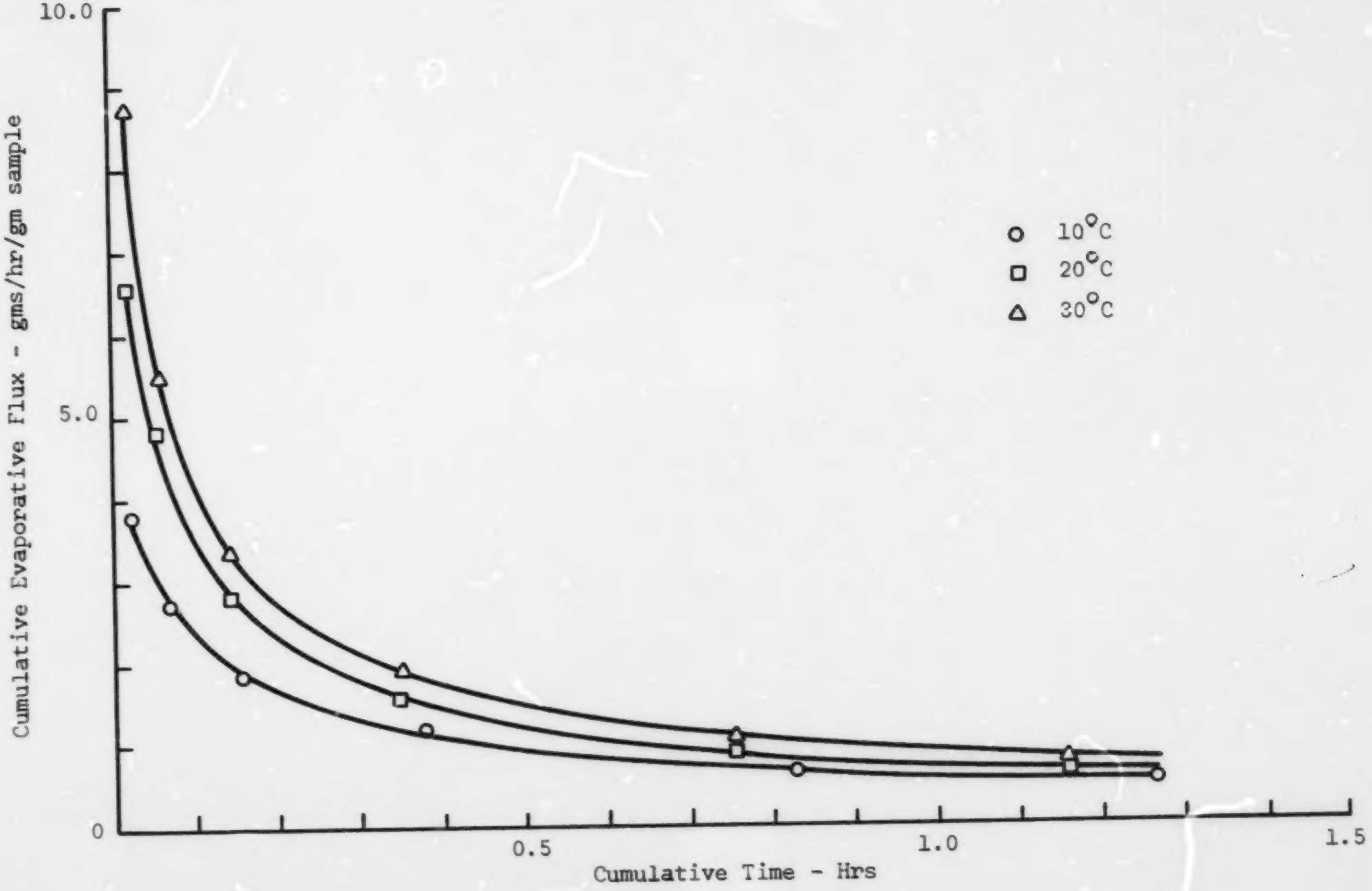


Figure 78 - Cumulative Evaporative Flux - Gasoline plus Oil

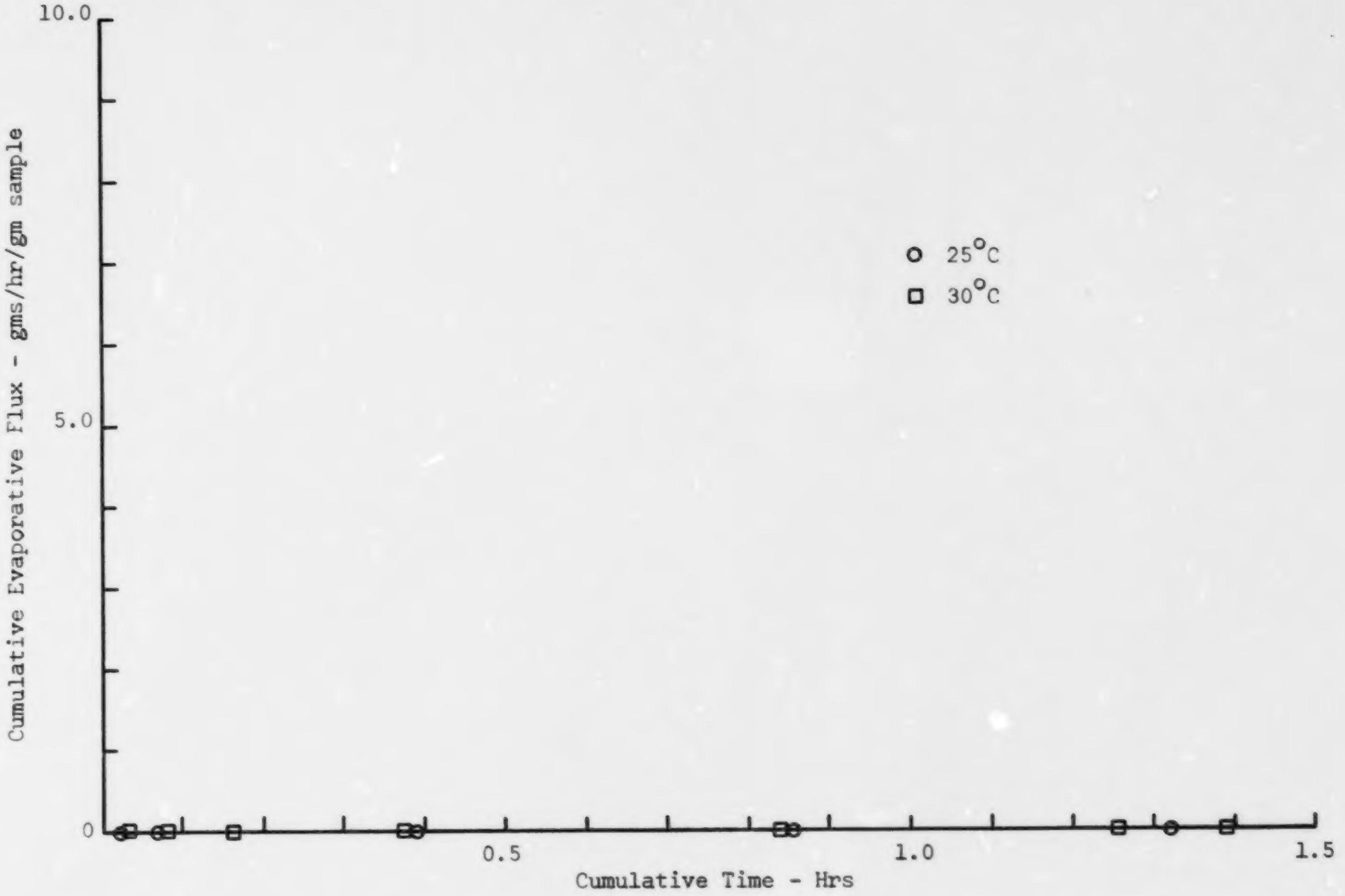


Figure 79 - Cumulative Evaporative Flux - Straight Oil

exhaust products considered would be proportional to the area of surface exposed to the air, the rate has been expressed as grams of material evaporated per unit time per gram of sample, or a true evaporative flux.

It will be noted from the tabulated results that percent evaporation had a high initial rate that fell off rapidly as a function of time, and approached a steady value. Correspondingly, the evaporative flux had high initial values which decreased with time. The evaporative rates increased with an increase in temperature.

It will be noted by comparison of results that for any given temperature the highest evaporation rates were encountered with the straight gasoline. Mixtures of gasoline and oil as used in the fuel gave evaporation rates only slightly lower, as might be expected. The evaporation rates for the exhaust products used in this study are intermediate between those of the fuel mixture, and the almost negligible rates found for the straight oil.

A significant feature of these results is that a considerable fraction of the exhaust products can be expected to evaporate from the water surface to the air at temperatures normally encountered during periods of the year when boating is at a maximum level. Indeed, it would appear quite likely that evaporation may be the controlling mechanism for determining the fate of the considerable low-boiling fraction of the exhaust products. It should be noted, however, that various significant fractions of exhaust products remain to interact with the lake environment by various other mechanisms.

It should be noted that the evaporation rates reported here must be considered specific to the materials and conditions used in these tests. It would be expected that other gas/oil ratios, other brands of fuels, other engines and other operating conditions would give different specific rates. The trends reported here, however, are considered to be significant and typical of the rates of evaporation to be expected of the exhaust products discharged.

SECTION XII - STUDY OF CURRENTS

In order to determine whether surface and sub-surface currents played a significant role in either the accumulation or dispersion of films of exhaust products, a series of tests were made to examine the nature and magnitude of currents in Dunham Bay, Echo Bay and Smith Bay.

It was originally planned to use a dye technique for these studies. Initial tests, however, indicated that this method was unsuitable with the equipment available at the time. Upon the advice of the New York State Environmental Conservation Department, a method of floating bottles was employed for surface measurements. In addition, a device was developed for indicating sub-surface currents. The device was lowered through holes in the ice at selected stations in the bays, during the winter season.

The bottle tests were made by using 250 ml polyethylene bottles that were partially filled with water. This caused the bottles to attain a position such that less than 1/2 inch of the diameter of the bottle was above the surface of the water, thus minimizing direct effects of the wind on the bottles. Bottles were painted a vivid orange to assist in future sightings.

A dispersion study was made in Smith Bay to determine the validity of using single bottles to represent the behavior of specific areas of the water surface. Tests were made by setting bottles, usually fifteen in number, in a circle of about two feet in diameter, and allowing the bottles to travel freely. After a measured time period, usually one or one and a half hours, the dispersion was noted by observing the position of individual bottles and the general size and shape of the original circle. The rate and type of dispersion, of course, depended somewhat on weather conditions. It was found, in general, that circles of bottles up to about 25 feet in diameter essentially retained their identity within the confines of the test bay. The circles tended to deform to an eliptical shape with the longer axis in the direction of flow.

The position of individual bottles as a function of time was determined by measuring position angles from certain fixed points. These positions were used for plotting on maps of the bays.

Data collected for the three bays are shown in Tables 63-65, in the form of field notes. The angles referred to are with reference to the sighting points shown in Figs. 80-82, respectively.

Some interesting observations are apparent from these tests. In almost all cases the trend of the currents on the surface was into the bays regardless of the wind direction, except under extreme conditions. While not measured in this aspect of the study, it was strongly suspected that there was somewhat of a trend for outward flow beneath the surface. This was verified by sub-surface measurements. It was also noted that the

Table 63

Current Studies - Field Notes and Observations

Smith Bay - June 16, 1972

Bottle No.	Drop Time	Drop <1 L	Drop <2 R	Pick-up Time	Pick-up <1-L	Pick-up <2-R
16	11:25	110-1	180-2			
17	11:30	93-1	inner 140-2	12:07 S.dock S.L. West		
18	11:30	19-1	inner 85-2	12:10 See Note		
19	11:31	72-2	31-3	12:55	139-2	126-3
20	11:32	0-3	35-2	See Note		
21	11:33	61-2	13-3	See Note		
22	11:35	120-2	59-3	See Note		
23	11:37	169-2	133-1			
24	11:38	101-2	71-3			
25	11:40	50-2	31-3	12:59	160-5	91-3
26	11:42	135-3	0-4			
27	11:45	120-3	0-4	1:05	109-5	71-3
28	11:47	125-2	0-4	Same as 27		
29	11:48	125-2	10-4	1:00	129-4 facing out	16-5
30	11:50	91-2	19-3			See Note

Note: By Poplar Tree - 12:35
Except 30 - 12:40

No boat traffic occurred throughout entire testing period (11:25-1:05). Several bottles not found during tested period were found in bay during the next two weeks by the roadside, thus indicating the direction of flow was into bay on surface regardless of wind direction which had changed throughout the two week period, or the heavy flow of water in the stream at the roadside due to the heavy rains.

The bottles floated at a slight incline to the surface and generally perpendicular to the direction of flow. Less than 1/2" of the diameter of the bottle was above the surface, thus making negligible the effects of wind directly upon the bottle.

During the tests the wind generally followed the shape of the bay leaving the bay in an easterly direction.

Table 64

Current Studies - Field Notes and Observations

Echo Bay - June 27, 1972

Bottle No.	Time Out	Left	Cen.	Right	Time In	Left	Cen.	Right
35	9:51	0-1	121-B	180-2	1:02	Shore south side		
40	9:52	0-1	109-B	180-2	1:33	50-1	95-2	100-B
38	9:55	30-1	117-B	155-2	1:27	63-3	105-B	123-4
36	9:58	0-3	102-B	175-4				
32	10:00	14-3	109-B	180-4	12:25	63-3	105-B	123-4
33	10:01	0-3	90-B	180-4	12:23	70-5	113-3	130-6
45	10:05	0-5	89-4	180-6	1:44	7-7	57-5	76-6
43	10:06	20-5	130-4	190-6	2:00	By island bridge		
34	10:07	15-5	115-4	160-6				
28	10:13	0-7	45-5	145-8	11:00	Point 7		
44	10:14	17-7	63-5	170-8	11:00	Point 7		
42	10:14	25-7	75-5	180-8	11:00	Point 7		
41	10:16	25-7	60-5	165-8	11:00	Point 7		
18	10:44	3-7	83-5	105-6	2:00	By island bridge		

A 5-10 mph wind from south occurred in lake. The wind was at a much lower velocity in the bay.

The bottles were laid out in four lines across the bay and allowed to float from 9:50 until 2:00 p.m.

Bottles in the bay drifted outwards and towards the shore. Those in the outlet of the bay at first drifted inward and then reversed their direction.

The boat traffic was moderate with 25-30 boats coming into or out of the bay during the test period. One bottle, which we were unable to find the day of the test, was recovered near the marina the following day with its number destroyed. The flow in the center of the bay displayed an overall outward flow whereas that along the shore was toward the shore.

Table 65

Current Studies - Field Notes and Observations

Dunham Bay - June 29, 1972

Bottle No.	Time In	Right	Cen.	Left	Time Out	Right	Cen.	Left
32	10:19	166-6	84-5	3-4				
40	10:20	Bridge			11:45	In Swamp		
41	10:20	Bridge			11:45	In Swamp		
18	10:20	Bridge			11:45	In Swamp		
35	10:20	Bridge			11:45	In Swamp		
33	10:23	169-5	109-5	+1-4	2:05	90-4	83-3	57-3
38	10:25	149-6	108-5	-1-4	2:00	98-2[SL]	50-9[a]	22-4
30	10:27	144-5	53-4	26-3	3:17	90-7	71-4	55-2
43	10:29	144-5	81-4	46-3[a]	2:25	Point 9		
37	10:31	152-5	102-4	66-3[a]				
45	10:33	Point 3----------------[a]						
21	10:34	Point 2----------------			2:40	100-5	74-4	56-3
28	10:37	143-7	100-5	76-4	2:37	87-7[SL]	68-5	42-3
44	10:38	153-7	96-5	71-4	1:35	117-8[SL]	94-7	86-3[a]
26	10:40	140-7	80-5	55-4	1:40	105-8	82-7	71-3[a] [a]
20	10:41	Off Point 7						
39	10:42	Off Point 8						
42	10:45	100-3	77-2	27-1	1:52	112-8	82-3	48-1
23	10:46	172-8[a]	84-3	9-1	1:40	122-8	95-3[a]	61-1
15	10:48	135-7	114-3[a]	43-1				
19	10:51	92-7	57-2	11-1	1:14	82-8	64-7	57-4
5	10:58	Point 1						
22	11:00	Bridge			11:45	Point 6		
27	11:00	Bridge			2:10	111-6	66-4	30-3
29	11:00	Bridge						

Very light wind from southeast.

Moderate boat traffic. One-hundred boats throughout test period.

The bottles were laid out in three lines across the bay and in two groups in front of the bridge where the stream enters the bay.

As in Echo Bay, the bottles in the center of the bay tended to drift outward and those on the sides tended to drift to the shore and remain there.

It is interesting to note that those placed in front of the stream outlet ended up in the nearby swampy area.

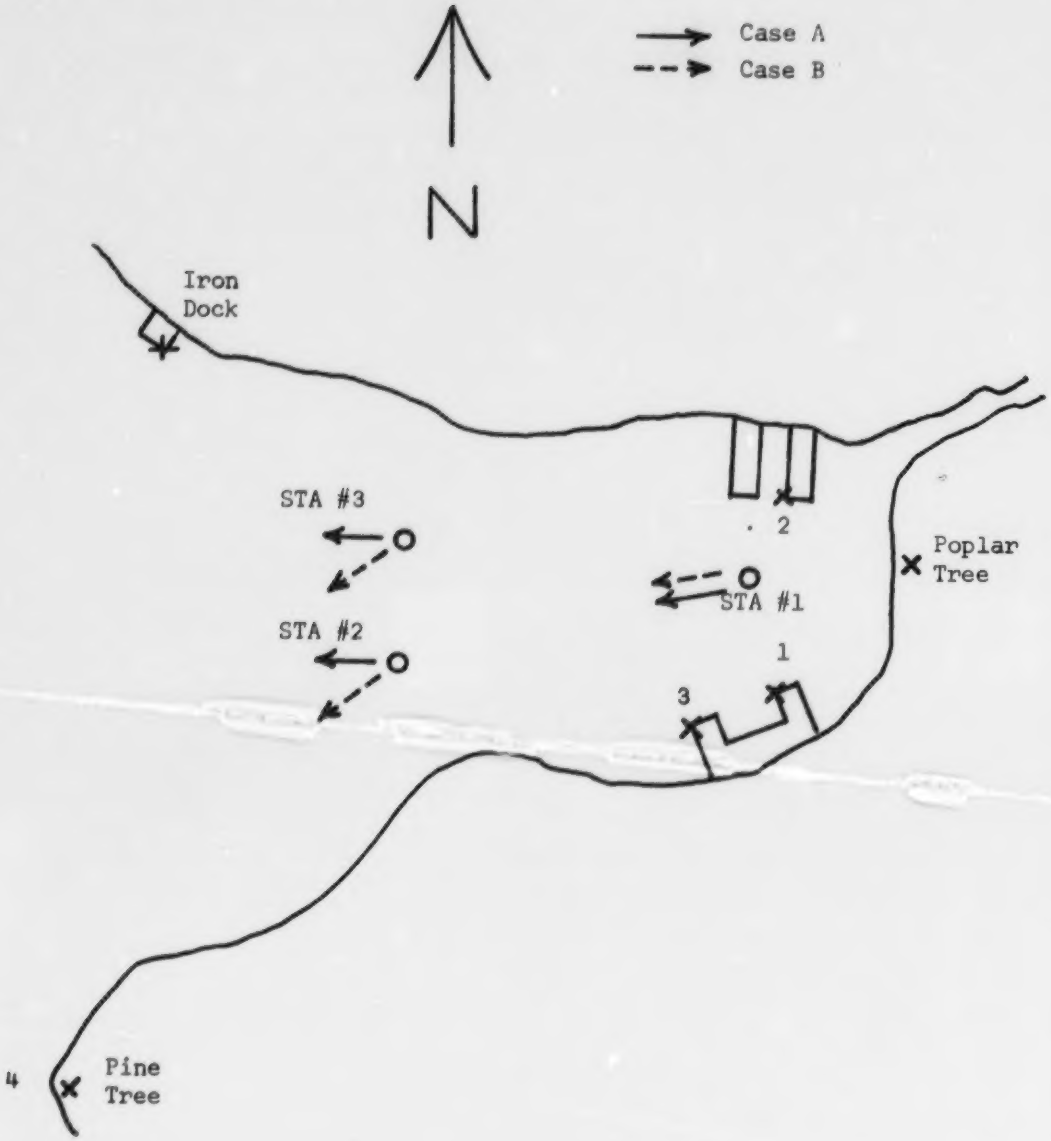
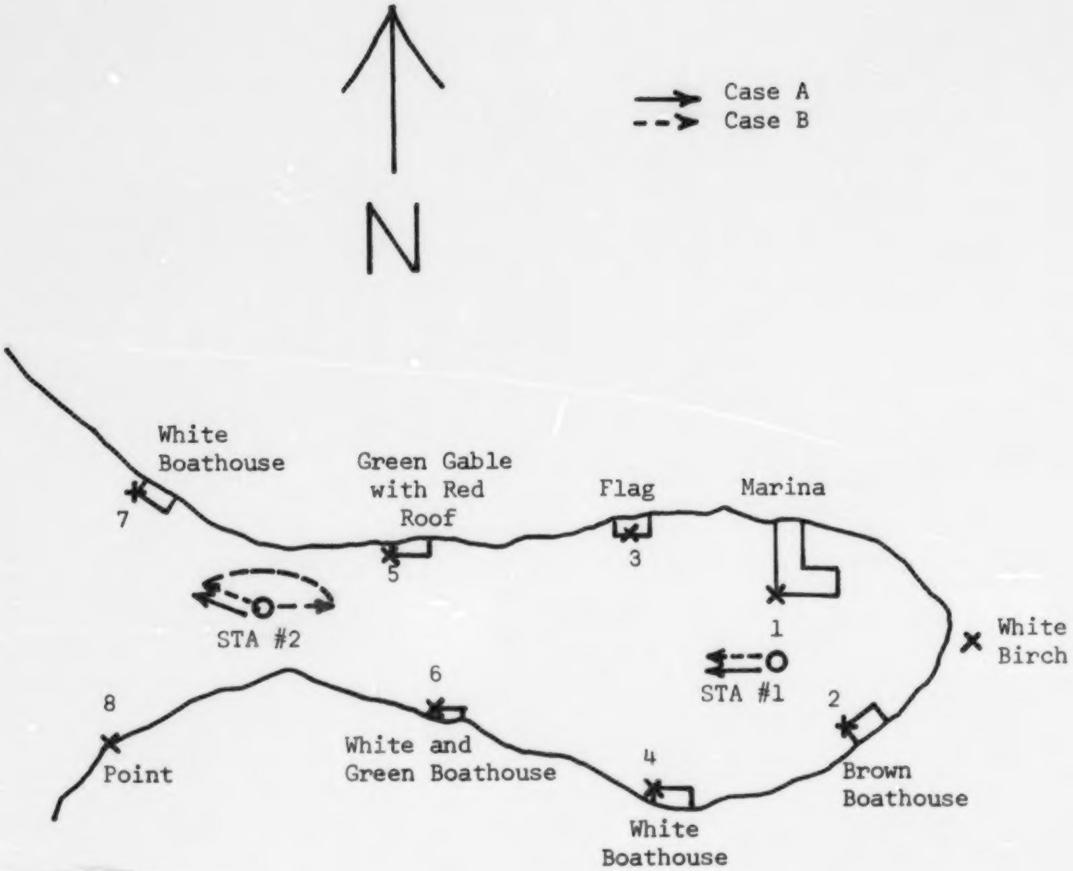

Case A
Case B
N
Iron
Dock
STA #3
STA #2
STA #1
2
1
3
Poplar
Tree
4
Pine
Tree

Figure 80 - Sketch of Smith Bay with the Approximate Location of Sighting Points



N
Case A
Case B
White Boathouse
7
Green Gable with Red Roof
5
Flag
3
Marina
1
White Birch
STA #2
STA #1
6
8
Point
White and Green Boathouse
4
White Boathouse
2
Brown Boathouse

Figure 81 - Sketch of Echo Bay with the Approximate Location of Sighting Points

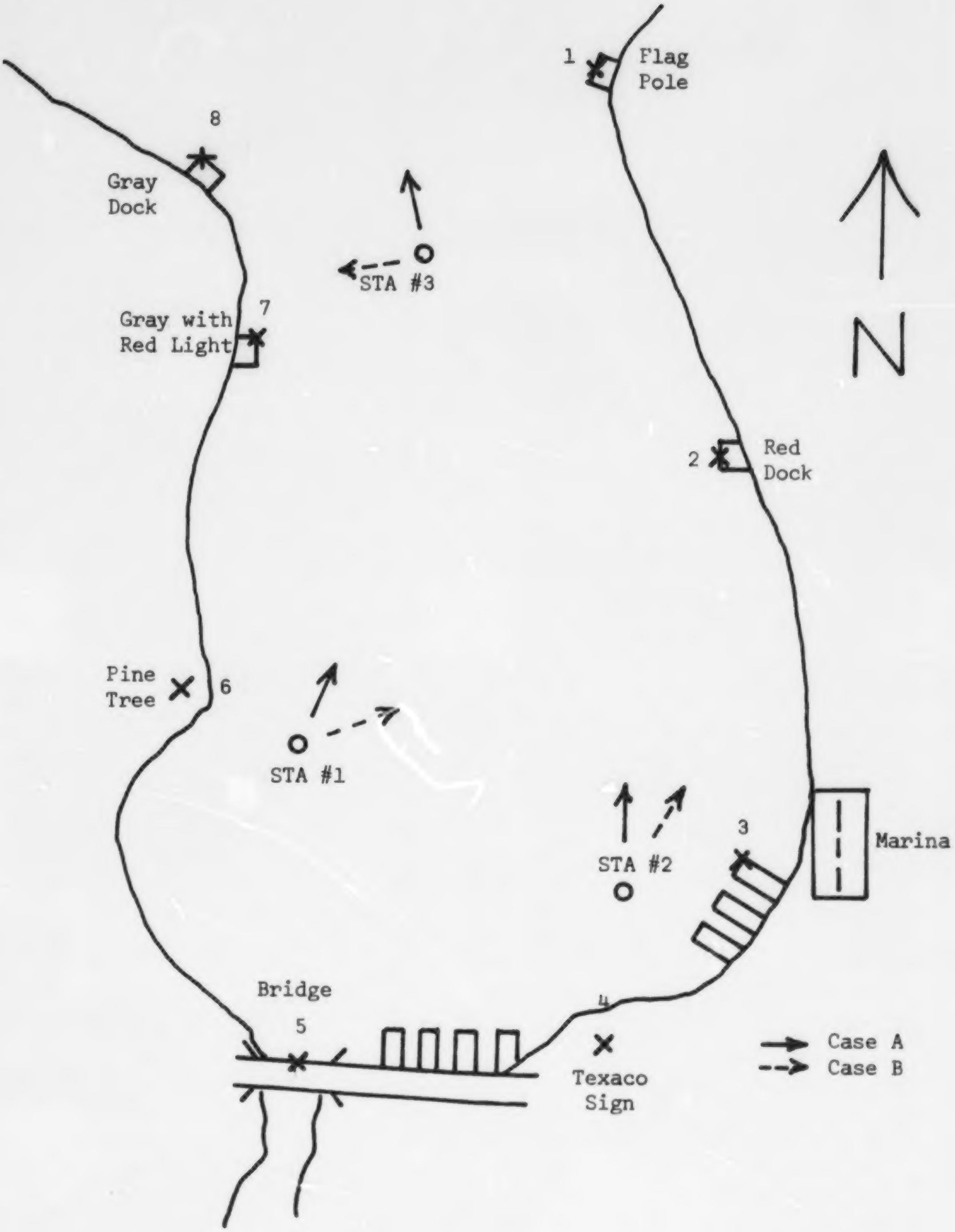

1
Flag
Pole
8
Gray
Dock
STA #3
Gray with
Red Light
7
N
2
Red
Dock
Pine
Tree
6
STA #1
3
Marina
STA #2
Bridge
5
4
Texaco
Sign
Case A
Case B

Figure 82 - Sketch of Dunham Bay with Approximate Location of Sighting Points

test bottles moved towards the shore, with the rate decreasing as distance from the shore decreased. These results reinforce the observations made elsewhere that an appreciable portion of oil slicks tend to move towards the shore and is deposited upon materials at the shoreline (40). For the test bays used in this study, there did not appear to be appreciable dispersal of surface materials out into the body of the lake under conditions noted.

During the winter of 1972, a current-indicating device was built and used to observe the direction of sub-surface currents at various stations in the test bays. A sketch of the instrument is shown in Fig. 83. The device consisted of a metal vane approximately 1 foot by 2 feet in size and 1/16 inch thick, attached to a vertical 6 foot section of Flexiframe rod. The rod was supported between two steel plates and pivoted at the pointed bottom end in a cup machined in the bottom plate. An indicating arm was attached to the vertical shaft and aligned with the vane to show the direction in which the vane was pointing at any instant. The whole device was supported on a tripod ringstand with provisions made for assuring that the shaft was in a vertical position.

The following is the procedure used in making observations:

1. A hole approximately 1 foot by 2 1/2 feet was cut in the ice with a chain saw.
2. Visual sitings of landmarks on shore were taken and recorded.
3. The current direction indicator was lowered through the ice and attached to the tripod ringstand by means of adjustable clamps in a relatively vertical position.
4. The shaft was then adjusted for plumbness by means of the rod that was attached to the shaft bearing.
5. The indicator was allowed to reach an equilibrium position and a compass reading was taken.

Readings were taken at the sites indicated in Figs. 80-82. The directions of the currents at the time of the readings are also indicated on these sketches. Observations were made at the sites during two periods when run-off was markedly different. Case A corresponded to a period of high run-off, while Case B corresponded to a period of minimum run-off.

As indicated in Fig. 82, the currents were found to be moving straight out of Dunham Bay during the period of high run-off. During low run-off, however, a counter-clockwise movement within the bay was observed. As shown in Fig. 81, the current in Echo Bay was outwards during the period of high run-off for both stations. During low run-off the flow was again outward at the inner station, but tended to oscillate through nearly 180° at the outer station. At the stations in Smith Bay, the currents were outward in all cases, as shown in Fig. 80. The directions, however, were somewhat more southerly at the outer stations during the period of low run-off.

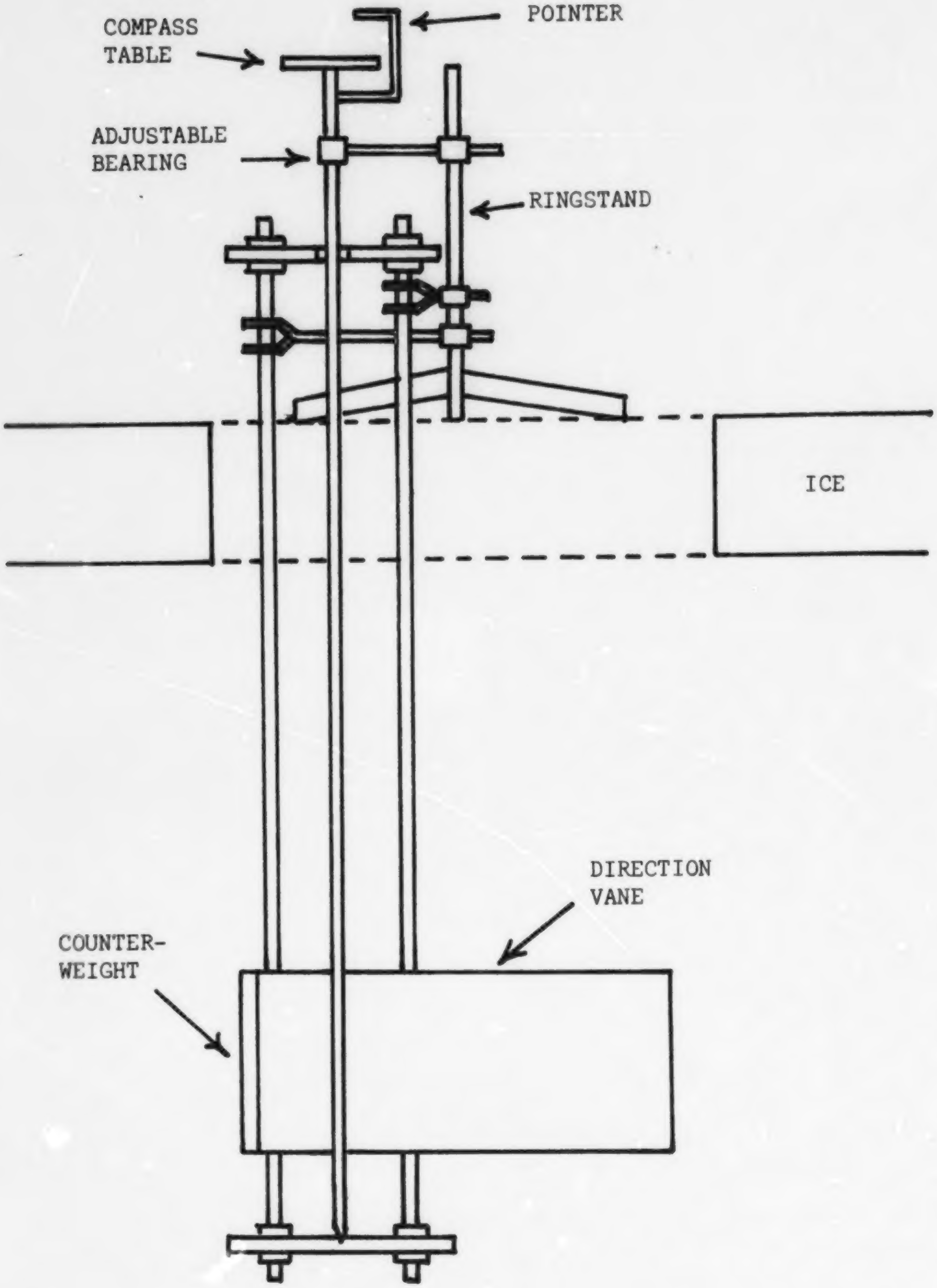

COMPASS TABLE
POINTER
ADJUSTABLE BEARING
RINGSTAND
ICE
DIRECTION VANE
COUNTER-WEIGHT

Figure 83 - Current Indicator

SECTION XIII - STATISTICAL ANALYSIS OF DATA

INTRODUCTION

In this section the kinds of statistical analyses of the data, discussed in the previous sections, are described.

The thrust of this section is to identify the components of the lake system which tended to explain the variation of the "component of interest". For instance, if the level of phytoplankton is of interest, it would be identified as the response variable. The level of the response variable is postulated to be dependent upon the levels of certain other components of the lake system. In this analysis, such components are identified. It should be pointed out that any such identification does not imply any absolute cause and effect relationship. The reader must keep in mind that due to the nature of the data collection procedure, only those subsets of the data that were obtained during comparable time periods could be used for these different analyses. It is felt that these results are reasonable indicators of "possible" associations among variables. When no association is apparent, it could be due to sampling variation or the fact that the variables really are not correlated.

GENERAL APPROACH TO ANALYSIS

The data were collected at three bays (Dunham, Echo and Smith Bays). At Dunham Bay there were three stations and at the other two bays there were two stations. For this work the bays were coded as 1, 0, and -1 for Dunham, Echo and Smith Bays, respectively. In the initial analyses the bays were coded using two dummy variables. The results of these analyses indicated that there were no significant differences due to bay. However, it must be pointed out that 1) in different analyses different subsets of data were used and 2) the number of observations were few. Hence, it was felt that the response variable should be adjusted for the bay, since the potential reduction in variance might be sufficient to warrant a loss of one degree of freedom. The coding given above was based on the fact that Dunham Bay has the maximum man-made loading and Smith Bay the least man-made loading.

For similar reasons the stations were coded 1, 0, and -1. The Julian date was used in the analyses.

In the analyses that follow, the response variable was first adjusted for Bay, Station and Day effects before attempting further analysis.

The population level of microorganisms was recoded by dividing the observed value by 1000.0. This scaling was necessary for computing efficiency.

MODELS

In the next paragraph, a detailed description of the model-building procedure is given. In general terms, the analysis was basically an attempt to build a model which will explain the behavior of the response variable. These models are not necessarily the "best" model in the true sense of the word. Instead, they are conditional on the data observed. Due to the fact that the degrees of freedom were small, no strong statements could be made about these models.

SELECTION OF INDEPENDENT VARIABLES

A very important aspect of this analysis is the procedure by which the components that explain the variation of the response variable are selected. Based upon the knowledge of the lake chemistry and biota, the possible independent variables are selected.

After correcting the response variable for Bay, Station and Day (hereafter referred to as concomitant variables), the partial correlations of the remaining variables with the corrected response is studied. The one which explains the greatest amount of the variation are introduced into the equation. While there is no fixed level of significance, the probability of such a contribution towards explaining the variance is considered and depending upon one's willingness to accept certain levels of risk, the variable is either selected or rejected. For phytoplankton, the selection procedure is explained in detail. For the other variables, only the summary of the analysis and conclusions are presented.

In order to facilitate easy cross-reference and continuity, the following sections are organized according to important response variables. In each section, the results are presented as relation to the independent variables which were felt to be of primary importance.

RELATION BETWEEN PHYTOPLANKTON, COLUMN MICROORGANISMS, COLUMN DISSOLVED OXYGEN, COLUMN TEMPERATURE AND HYDROCARBON LEVEL

In this section the association between phytoplankton and column microorganisms, column dissolved oxygen, column temperature and hydrocarbon levels are investigated.

As stated earlier, the concomitant variables, Bay, Station and Day, were entered. It should be noted that simultaneously observed data on the variables of interest are available only on seven days. The over-all means and standard deviations are given in Table 66a.

Table 66a

Over-All Means and Standard Deviations of Variables

Variable	Mean	Std. Dev.
Column Microorganisms	3.8	4.5
Column Temperature	20.2	2.21
Column Dissolved Oxygen	8.3	0.69

Figs. 84 & 85 are plots of temperature against Log (phytoplankton) for Echo and Dunham Bays. Again, it should be noted that most of the points are clustered in the range from 1 to 5.

The natural logarithm (Log) of phytoplankton was used. Based on theoretical studies, it was suggested that such a logarithmic transformation would convert phytoplankton to an appropriate scale for analysis. Subsequent analysis supported this idea.

For the total of 19 cases examined, the block variables consisting of Bay, Station and Day explained about 11% of the variation in the response variable. After removing the effect due to these variables, the partial correlations of the variables with the response variable are given in Table 66g. The means and standard deviations for the various bays and stations are presented in Tables 66b-66f. These descriptive statistics have not been corrected for Day. Hence, some of the apparent differences may be due to this.

Table 66b

Means and Standard Deviations of Log (Phytoplankton)

	Echo Bay			Dunham Bay		
	Mean	Std. Dev.	N*	Mean	Std. Dev.	N*
STATION 3	--	--	--	3.08	0.83	4
STATION 2	1.22	4.03	5	3.12	0.07	3
STATION 1	1.22	3.52	7	--	--	--

*no. of points

Table 66c

Means and Standard Deviations of Hydrocarbon Level

	Echo Bay			Dunham Bay		
	Mean	Std. Dev.	N	Mean	Std. Dev.	N
STATION 3	--	--	--	3.63	2.29	4
STATION 2	3.26	2.19	5	3.86	2.78	3
STATION 1	3.2	1.44	7	--	--	--

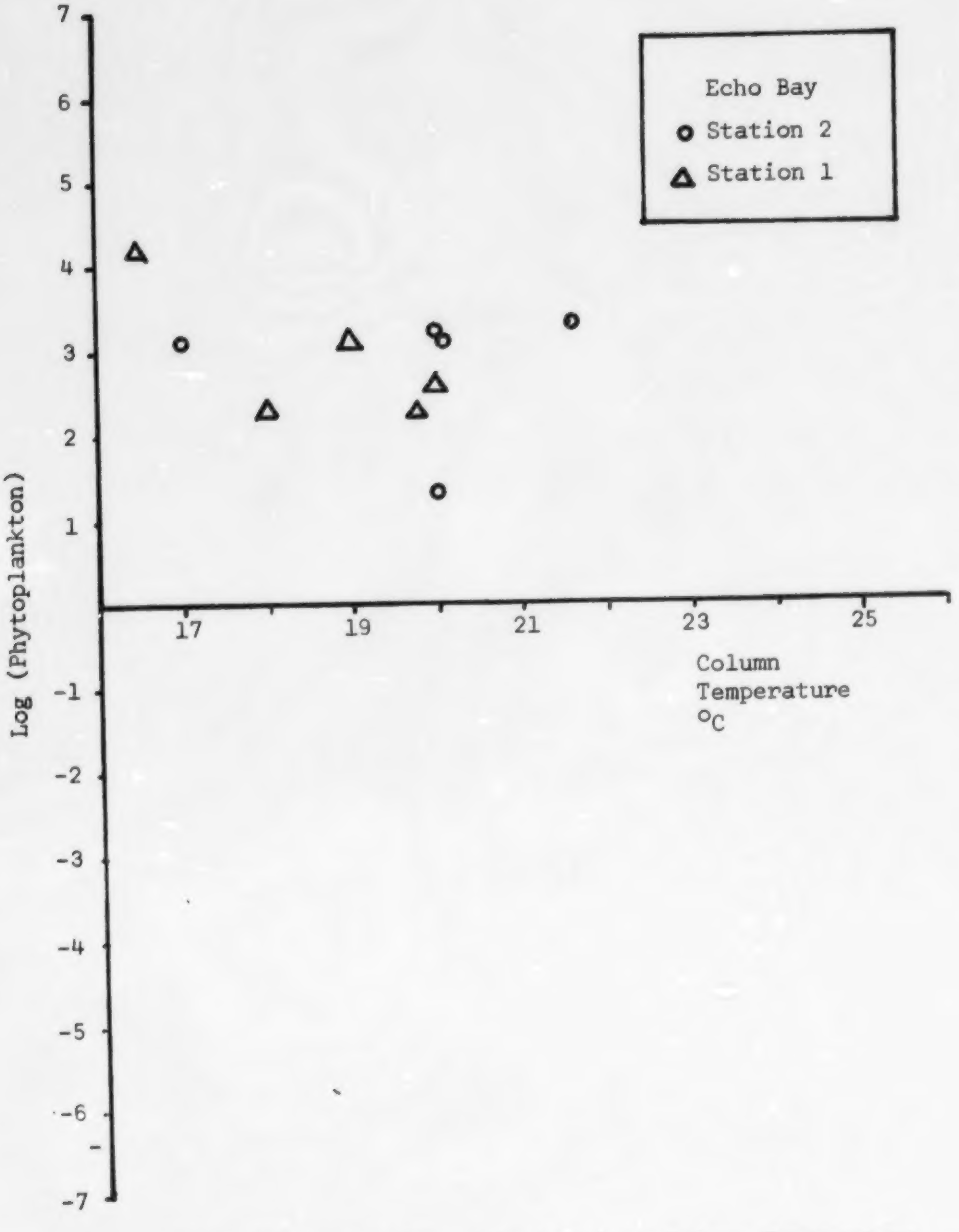


Figure 84 - Log (Phytoplankton) vs Column Temperature for Echo Bay, Stations 2 and 1

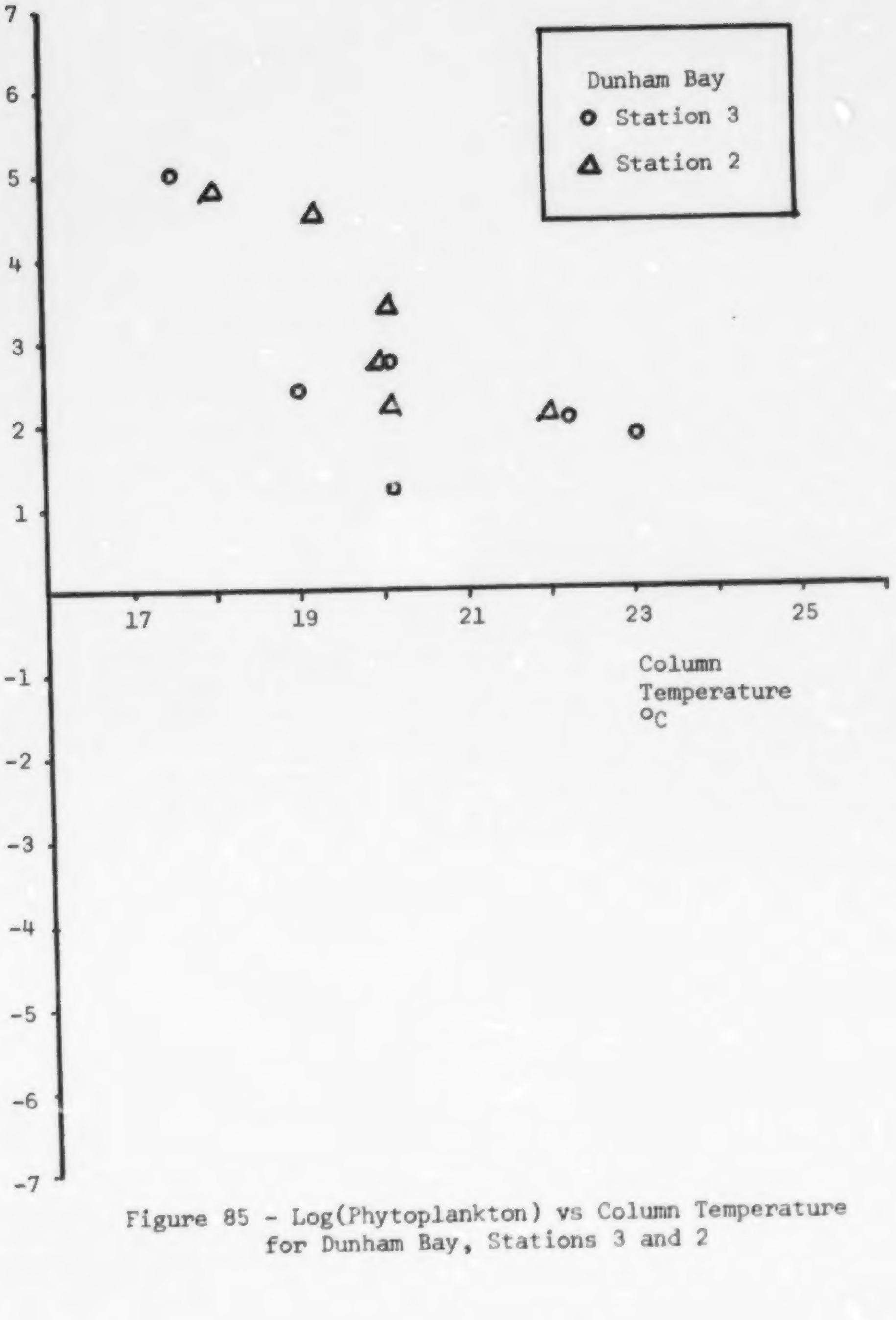


Figure 85 - Log(Phytoplankton) vs Column Temperature for Dunham Bay, Stations 3 and 2

Table 66d

Means and Standard Deviations of Column Microorganisms

	Echo Bay			Dunham Bay		
	Mean	Std. Dev.	N	Mean	Std. Dev.	N
STATION 3	--	--	--	0.325	0.45	4
STATION 2	4.6	4.93	5	0.667	0.57	3
STATION 1	6.0	4.98	7	--	--	--

Table 66e

Means and Standard Deviations of Column Temperature

	Echo Bay			Dunham Bay		
	Mean	Std. Dev.	N	Mean	Std. Dev.	N
STATION 3	--	--	--	18.33	1.44	4
STATION 2	21.2	2.61	5	19.0	1.82	3
STATION 1	21.1	2.59	7	--	--	--

Table 66f

Means and Standard Deviations of Column Dissolved Oxygen

	Echo Bay			Dunham Bay		
	Mean	Std. Dev.	N	Mean	Std. Dev.	N
STATION 3	--	--	--	8.15	0.11	4
STATION 2	8.56	0.89	5	7.97	0.25	3
STATION 1	8.21	0.83	7	--	--	--

Table 66g

Partial Correlation After Adjusting for Concomitant Variables

Variable	Partial Corr.	F-value
Hydrocarbon	-0.475	4.08
Column Microorganisms	-0.150	0.32
Column Temperature	-0.814	27.43
Column Dissolved Oxygen	-0.286	1.24

As can be seen from Table 66g, column temperature is highly correlated with phytoplankton levels. The probability that the F-value is as large or larger due to chance is less than .001. In other words, the probability that the sum of squares due to temperature being 92.79 or larger if there is no relationship with phytoplankton is less than .001. Hence, temperature is said to explain a significant amount of the variation in the response variable.

This principle is used throughout the analysis to determine whether a given variable could be considered to account for a significant amount of the variability observed in the response variable.

On adjusting the response (phytoplankton) for temperature, the current model explains about 70% of the variation in the response variable.

The correlation of the remaining variables with the phytoplankton corrected for the concomitant variables and temperature is given in Table 73.

Table 66h

Partial Correlation After Adjusting for Temperature

Variable	Partial Corr.	F-value
Hydrocarbon	0.09	0.10
Column Microorganisms	0.46	3.57
Column Dissolved Oxygen	-0.60	7.45

It should be noted that the partial correlation of hydrocarbon (HC) has dropped from -0.48 to 0.09. Apparently after removal of the variability associated with temperature, the variability remaining that can be associated with HC has been drastically reduced. In other words, the large experimental error in the measurement of HC has masked any association that might exist between HC levels and the log (phytoplankton) after correcting for temperature.

Again, the probability that the sum of squares due to dissolved oxygen being 17.249 or larger is less than .025. Hence, the response variable is adjusted for dissolved oxygen. At this point, it must be noted that the association with the time variable becomes significant. That is, on removing the effects due to Bay, Station, Temperature and Dissolved Oxygen, the association with Day becomes "visible".

The partial correlations of the remaining variables are given in Table 66i.

Table 66i

Partial Correlations After Adjusting for Dissolved Oxygen

Variable	Partial Corr.	F (Partial)
Hydrocarbon	0.1	0.13
Column Microorganisms	0.15	0.28

Table 66i shows that the contributions due to HC and column microorganisms are not significant.

The final model is summarized in Table 66j.

Table 66j

Summary of Results

Variable	Coefficient	Std. Dev.	Increase in R^2%	F-value	Significance Level
(Constant)	33.67	--	--	--	--
Bay	-0.340	1.23	9.91	0.0768	--
Day	0.052	0.02	0.90	5.77	0.05
Station	0.052	0.73	0.01	0.0052	--
Temp.	-1.132	0.173	59.05	42.57	0.001
D.O.	-2.334	0.855	10.98	7.4492	0.05

R^2 = 80.84; std. error of estimate = 1.52; degrees of freedom = 13

At this point the analysis is terminated. Further addition of variables to the model tends to increase the estimate of the variance of the estimated phytoplankton levels due to the small number of degrees of freedom.

Table 66j summarizes the results of the analysis.

The first column gives the name of the variable for which the response variable has been adjusted. The order in which the variables are listed is the order in which these variables were brought into the model. This order is important as will be explained later in this section.

The second column gives the coefficients in the model. For example, in this section the model is:

$$\begin{aligned}\text{Log(phytoplankton)} = {} & 33.498 + 0.170(\text{Bay}) + 0.052(\text{Station}) \\ & + 0.052(\text{Day}) - 1.132(\text{Temperature}) \\ & - 2.334(\text{Dissolved Oxygen}) + \text{Error}\end{aligned}$$

These values of the coefficients are the estimates of the true coefficient based upon the assumption that the form of the model relating the variables is reasonable.

The "error" at the end of the equation given above deserves some comments. By including such a term in the model, one is implying three important facts.

1) There are random variations of the response.
2) There might be other variables that are not in the model but maybe they should be.
3) The model representing the relationship among the included variables is inaccurate.

These coefficient estimates in the model are correlated to one another. This is due to the non-orthogenality of the data. Hence, one should be careful with such models. It would be inappropriate to assess the effect of the independent variables on the response variables separately. In other words, these coefficients have values which are conditional on the other independent variables being present in the model. It is quite possible that addition of some other factor or factors may affect the association between a given independent variable (already in the model) and the independent variable to such an extent that the variable may not be so important anymore in the model.

The third column in Table 66j gives the standard deviation of the coefficients in column two.

The fourth column gives the increase in R^2, where R is called the "multiple correlation coefficient". This coefficient R^2 is often stated as a percentage (as in this discussion). The coefficient is a measure of the fraction of the variability of the response variable that has been explained by the proposed model. A "true" model will give a R^2 close to 100%. In the fourth column the additional percentage of the variability that has been explained due to the addition of that specific independent variable is given. It should be pointed out that this increase in R^2 always occurs when a new factor is brought into the model. Its magnitude is related not only to the degree of association of the independent variable to the response variable, but also to the form in which this variable is included in the model. However, the order in which that variable is brought in (that is the response variable is adjusted for that variable) will affect the value of this increase in R^2. This is mainly due to the non-orthogenality of the data, and hence, as explained earlier, one should not make statements about the contribution to R^2 by a given variable without qualifying them with the variables already in the model.

The fifth column gives the "partial F-values". In the previous pages the sum of squares due to a given variable after adjusting for certain specific variables was discussed. This F-value is the same sum of squares divided by the estimated residual variance. Instead of making

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The fifth column gives the "partial F-values". In the previous pages the sum of squares due to a given variable after adjusting for certain specific variables was discussed. This F-value is the same sum of squares divided by the estimated residual variance. Instead of making probability statements on the conditional sum of squares due to a given variable, one can equivalently talk about the partial F and the probability statement based on this statistic. This probability statement is given in the last column of Table 66j as significance level.

For example, the significance level for the variable, Day, is given as 0.05. This is equivalent to saying that the probability that the sum of squares due to Day (after adjusting the response variable for the other independent variables) has a given value (or greater) purely by chance if there exists an association between the two that is less than 0.05.

In the discussion the accuracy of these probability statements is dependent upon the assumption that the error indicated in the model is approximately normally distributed. With the sample size available, this assumption could not be shown to be unreasonable.

As Table 66j shows, the Log (phytoplankton) displays an apparent dependence upon the temperature and dissolved oxygen levels and when they increase, the level of phytoplankton decreases.

One should use care in applying the model given in Table 66j for predictive purposes, since the total number of points is only 19 and the observations taken over a total of seven days have not permitted any powerful model evaluation.

However, these results represent a reasonably good indication of possible relationships which might be worth investigating. Figures 86-89 are presented to show how the computed response variable compares with the observed response. With the available data the model appears to be reasonably good. In Figure 89 the confidence intervals and the prediction intervals are indicated.

These intervals are indicated on the figures as follows: The vertical line indicates the prediction interval at the point. The horizontal lines indicate the confidence interval of the true mean for that value of independent variables. The observed value of the response variable is denoted by "X" and the estimated value of the response variable is denoted by "O".

The confidence interval and the prediction interval can be interpreted as follows: Suppose repeated samples of the response variable are taken of the same size each time and at the same fixed values of the independent variables, as were used to determine the model obtained earlier. Then, of all the 90% confidence intervals constructed for the mean value of the response variable for a given value of the set of independent variables, 90% of these intervals will contain the true mean value of the response variable at the given point in the factor space. From a practical point of view, one can say that there is a 0.90 probability that the true mean value of the response variable at the given point lies between a_1 and a_2, where a_1 and a_2 are the values of the response variable as given by the horizontal lines in Fig. 89 for each point.

Model 1: Log(Phytoplankton) = 33.67 - 0.34(Bay) - 0.052(Station) + 0.052(Day) - 1.132(Temp) - 2.334(D.O.)

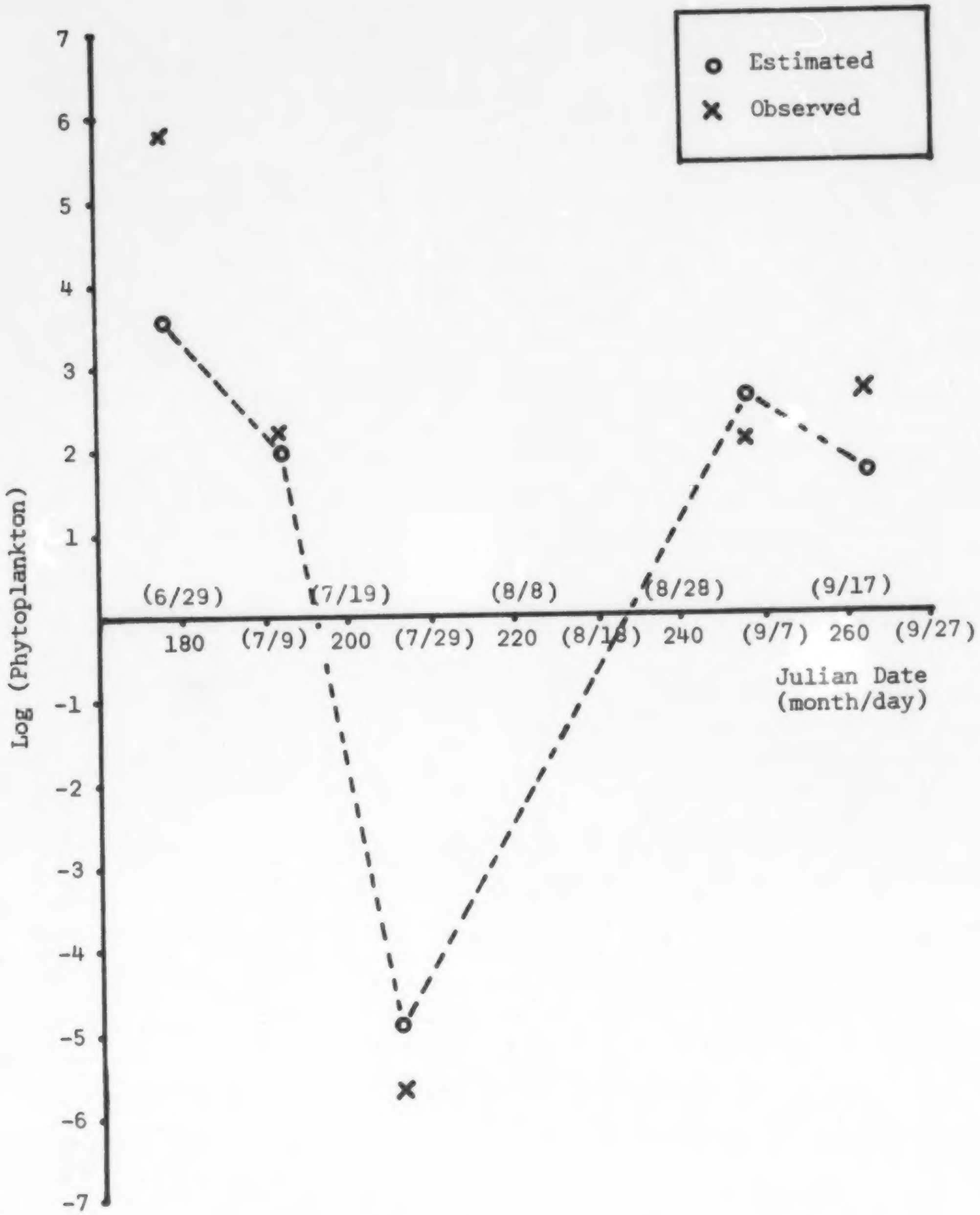

Figure 86 - Log(Phytoplankton) vs Julian Date for Echo Bay, Station 2, Model 1

Model 1: Log(Phytoplankton) = 33.67 - 0.34(Bay) + 0.052(Station) + 0.052(Day) - 1.132(Temp) - 2.334(D.O.)

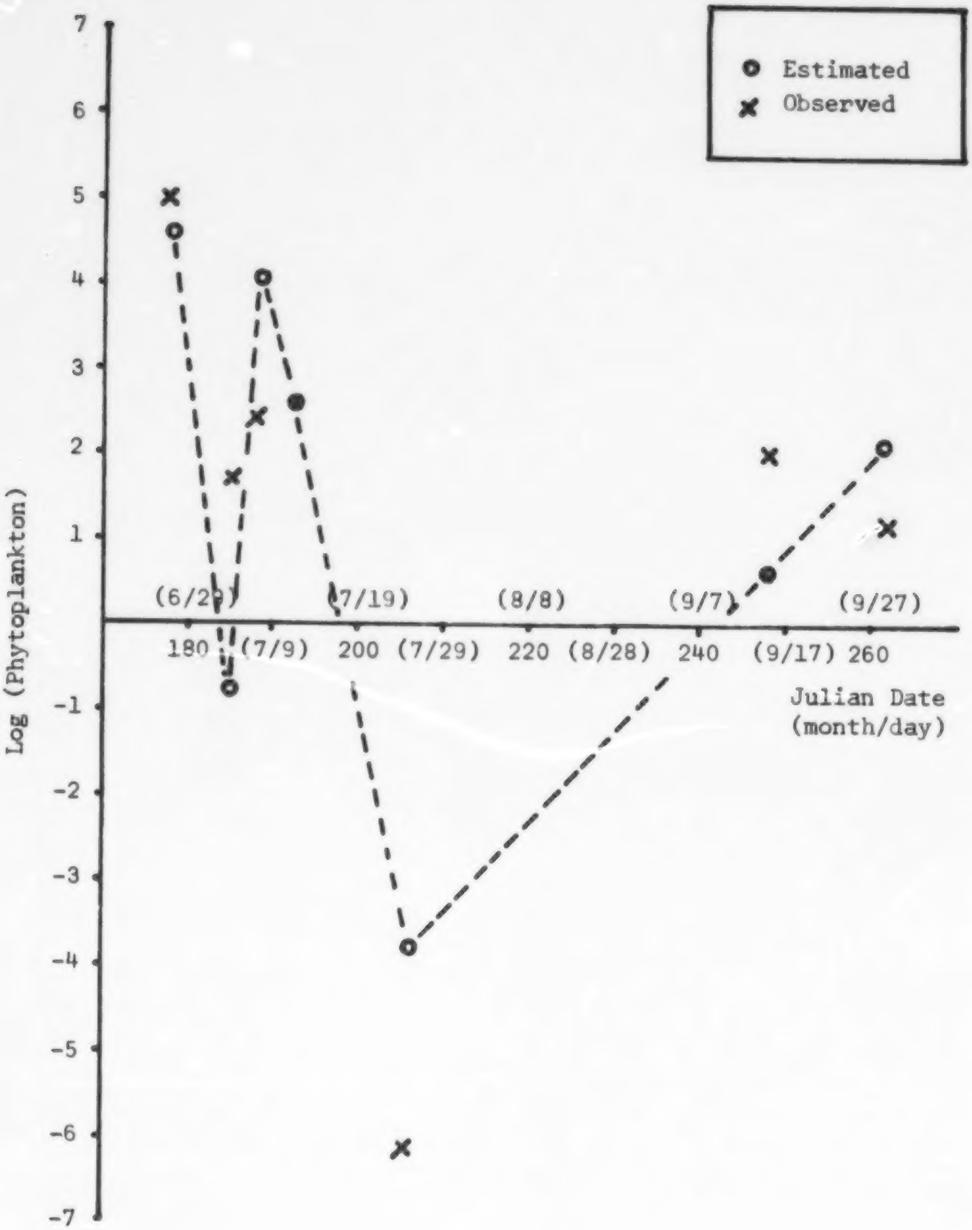

Figure 87 - Log(Phytoplankton) vs Julian Date for Echo Bay, Station 1, Model 1

Model 1: $\text{Log(Phytoplankton)} = 33.67 - 0.34(\text{Bay}) - 0.052(\text{Station}) + 0.052(\text{Day}) - 1.132(\text{Temp}) - 2.334(\text{D.O.})$

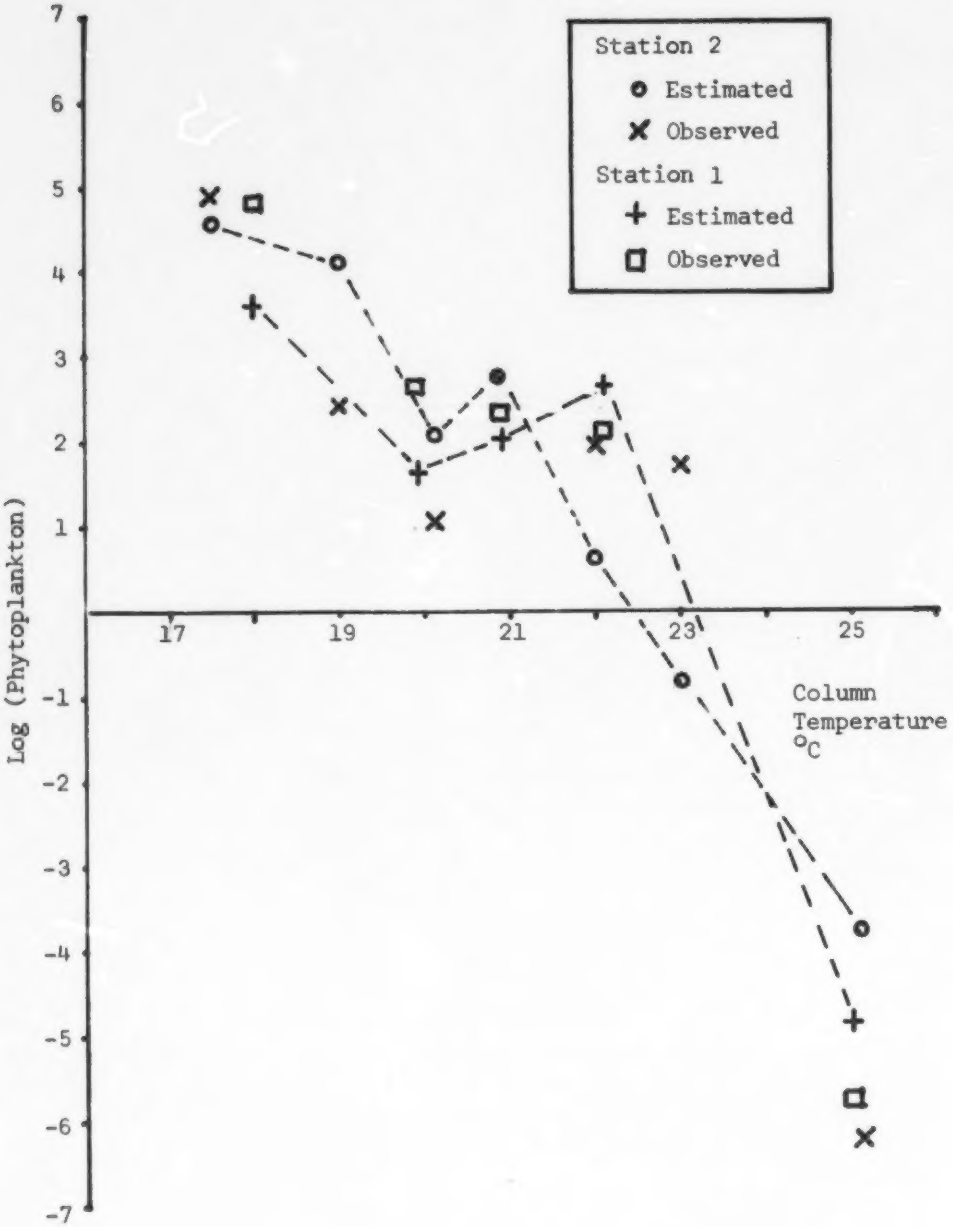

Figure 88 - Log(Phytoplankton) vs Temperature for Echo Bay, Stations 2 and 1, Model 1

Model 1: Log(Phytoplankton) = 33.67 - 0.34(Bay) - 0.052(Station) + 0.052(Day) - 1.132(Temp) - 2.334(D.O.)

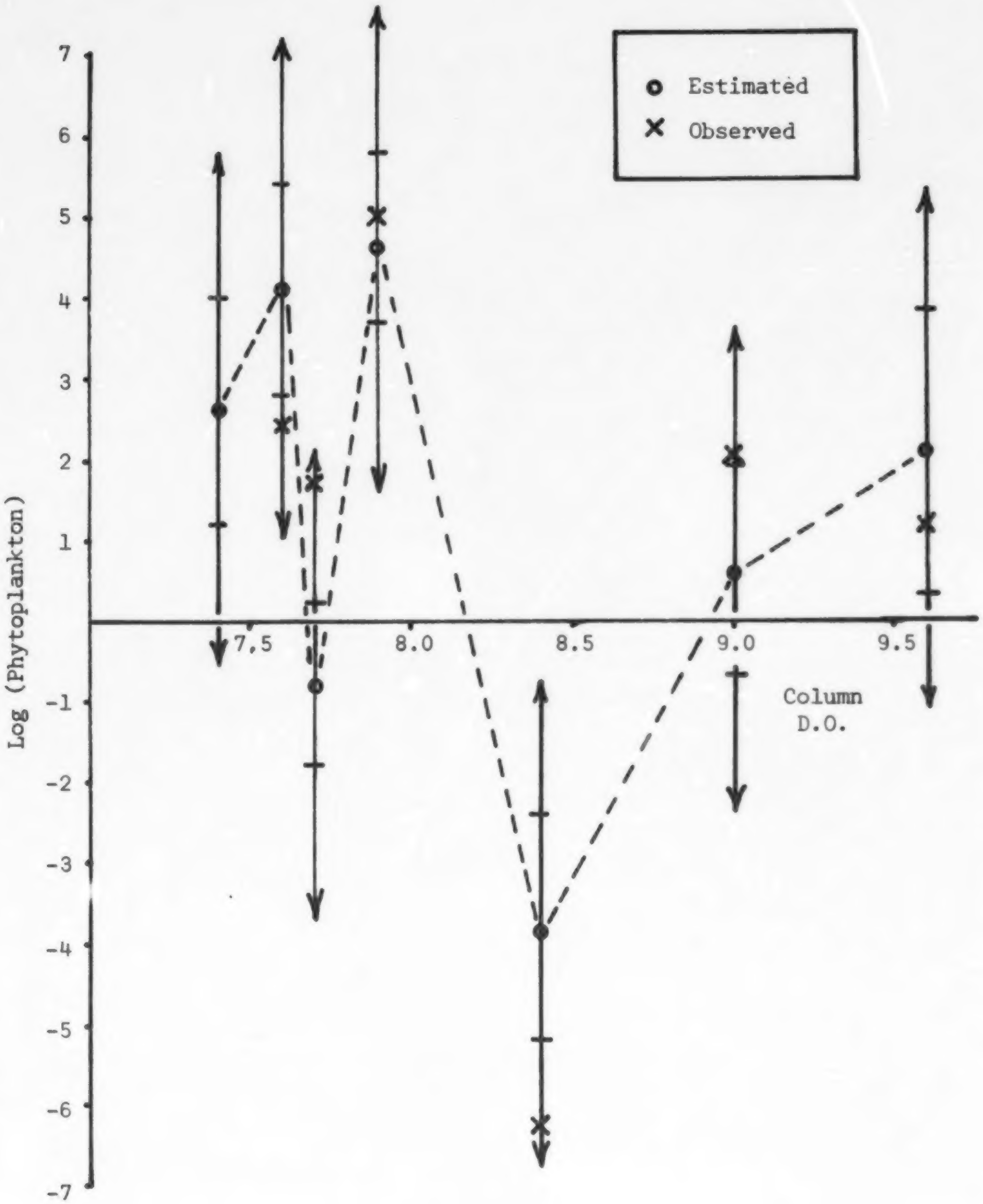

Figure 89 - Log(Phytoplankton) vs Dissolved Oxygen(Column) for Echo Bay, Station 1, Model 1

Furthermore, suppose a future observation is taken at a given point in the factor space. The probability that the future observation will lie within the prediction interval is given by 0.9.

In the discussion above, a probability of 0.9 has been chosen. Any other value of the probability can be chosen depending upon the risk one is willing to accept.

RELATION BETWEEN PHYTOPLANKTON, SURFACE MICROORGANISMS, SURFACE DISSOLVED OXYGEN, SURFACE TEMPERATURE AND HYDROCARBON LEVEL

In this section the association between phytoplankton and surface microorganisms, surface dissolved oxygen, surface temperature and hydrocarbon level are investigated.

As in the previous section, simultaneously observed data on the variables of interest are available for this analysis for only seven days.

The over-all means and standard deviations are given in Table 67a.

Table 67a

Over-All Means and Standard Deviations of Variables

Variable	Mean	Std. Dev.
Hydrocarbon	3.41	1.89
Surface Microorganisms	0.12	0.22
Surface Temperature	20.63	2.17
Surface Dissolved Oxygen	8.22	0.58
Phytoplankton*	1.91	2.95

*natural logarithm of phytoplankton levels

The readings were obtained from Echo Bay (12 observations) and Dunham Bay (7 observations).

The means and standard deviations for the "unadjusted" variables of interest are given in Tables 67b-67f. These are given for descriptive purposes only. They are not adjusted for Day. Hence, direct comparisons may be difficult because of this.

Table 67b

Means and Standard Deviations for Log (Phytoplankton)

	Echo Bay			Dunham Bay		
	Mean	Std. Dev.	N	Mean	Std. Dev.	N
STATION 3	--	--	--	3.08	0.83	4
STATION 2	1.22	4.03	5	3.12	0.06	3
STATION 1	1.22	3.52	7	--	--	--

Table 67c

Means and Standard Deviations for Hydrocarbon Level

	Echo Bay			Dunham Bay		
	Mean	Std. Dev.	N	Mean	Std. Dev.	N
STATION 3	--	--	--	3.63	2.29	4
STATION 2	3.26	2.19	5	3.86	2.78	3
STATION 1	3.2	2.08	7	--	--	--

Table 67d

Means and Standard Deviations of Surface Microorganisms

	Echo Bay			Dunham Bay		
	Mean	Std. Dev.	N	Mean	Std. Dev.	N
STATION 3	--	--	--	0.03	0.047	4
STATION 2	0.064	0.049	5	0.04	0.047	3
STATION 1	0.24	0.34	7	--	--	--

Table 67e

Means and Standard Deviations of Surface Temperature

	Echo Bay			Dunham Bay		
	Mean	Std. Dev.	N	Mean	Std. Dev.	N
STATION 3	--	--	--	19.6	1.22	4
STATION 2	21.14	2.45	5	19.4	1.97	3
STATION 1	21.36	2.41	7	--	--	--

Table 67f

Means and Standard Deviations of Surface Dissolved Oxygen

	Echo Bay			Dunham Bay		
	Mean	Std. Dev.	N	Mean	Std. Dev.	N
STATION 3	--	--	--	7.925	0.21	4
STATION 2	8.5	0.63	5	7.9	0.5	3
STATION 1	8.34	0.675	7	--	--	--

For the same reasons listed in the previous section, the natural logarithm of the phytoplankton was used in the analyses.

In Table 67g the final equation is given.

Table 67g

Summary of Results

Variable	Coefficient	Std. Dev.	Increase in R^2%	F-value	Significance Level
Bay	0.213	1.07	9.91	0.04	--
Day	0.022	0.02	0.90	1.38	--
Station	-0.77	0.66	0.01	1.87	--
Temp.	-0.744	0.20	61.37	13.41	0.005
Surf. Microorg.	-6.432	1.96	7.88	10.76	0.01
D.O.	-2.035	0.86	6.36	5.62	0.05
(Constant)	30.04	--	--	--	--

R^2 = 86.42; std. error of estimate = 1.33; degrees of freedom = 12

Table 67g indicates there might be correlations between Log (phytoplankton) and surface microorganisms, surface temperature and surface dissolved oxygen. Hydrocarbon does not seem to contain any significant information after phytoplankton has been adjusted for the other variables. The sum of squares due to hydrocarbon after adjusting for other variables is 0.687 and the probability of a value greater than 0.687 due to chance alone is more than 0.9. Hence, the evidence to include hydrocarbon in the model is insufficient. Also, it should be noted that the association with Day and Station is significant at about the 25% level.

Figs. 90-94 are presented to compare the performance of the model in the factor space under investigation.

Model 2: Log(Phytoplankton) = 30.04 + 0.213(Bay) - 0.77(Station) + 0.22(Day) - 0.744(Temp) + 6.43(Surface Microorganisms) - 2.035(D.O.)

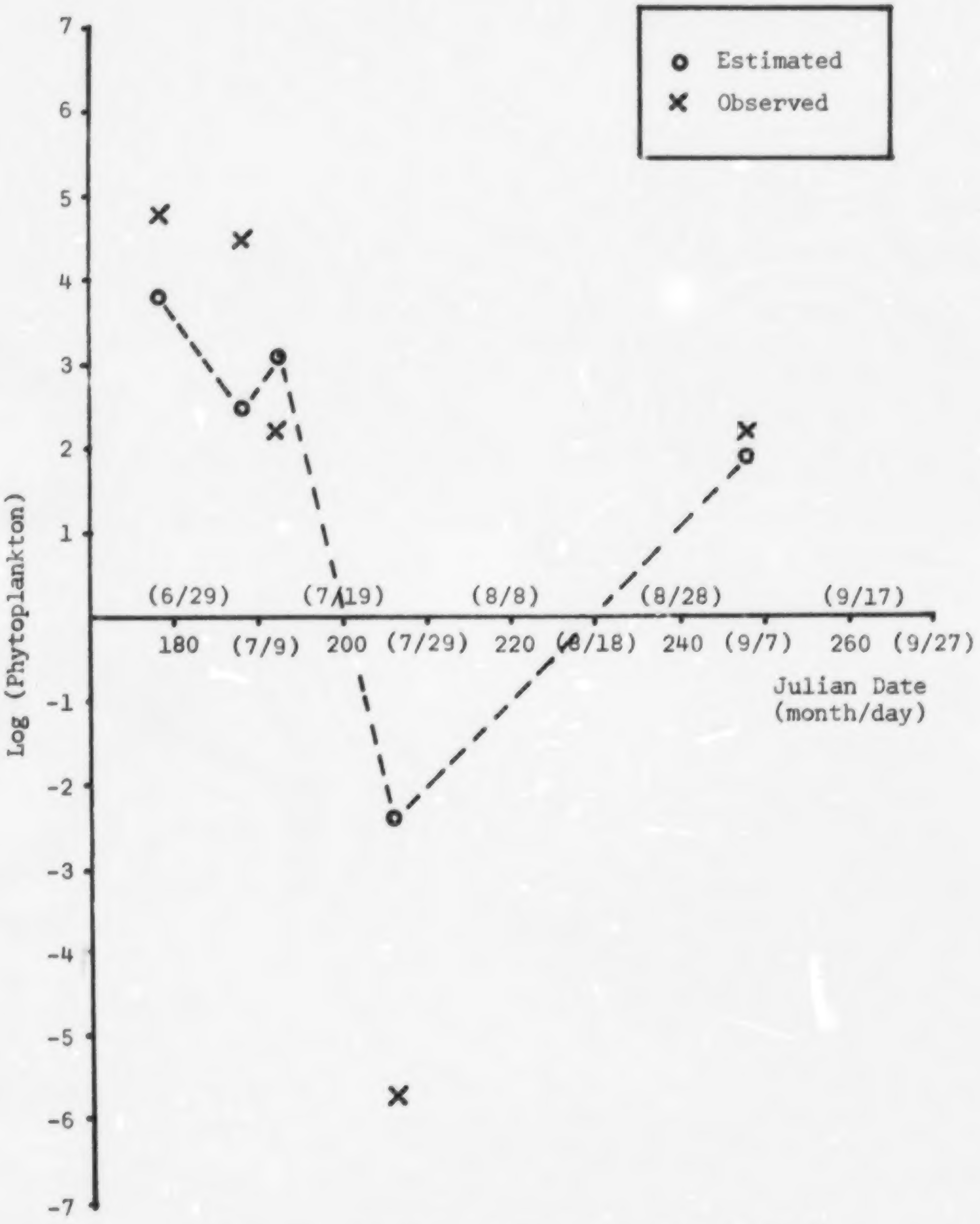

Figure 90 - Log(Phytoplankton) vs Julian Date for Echo Bay, Station 2, Model 2

Model 2: Log(Phytoplankton) = 30.04 + 0.213(Bay) - 0.77(Station)
+ 0.22(Day) - 0.744(Temp) + 6.43(Surface
Microorganisms) - 2.035(D.O.)

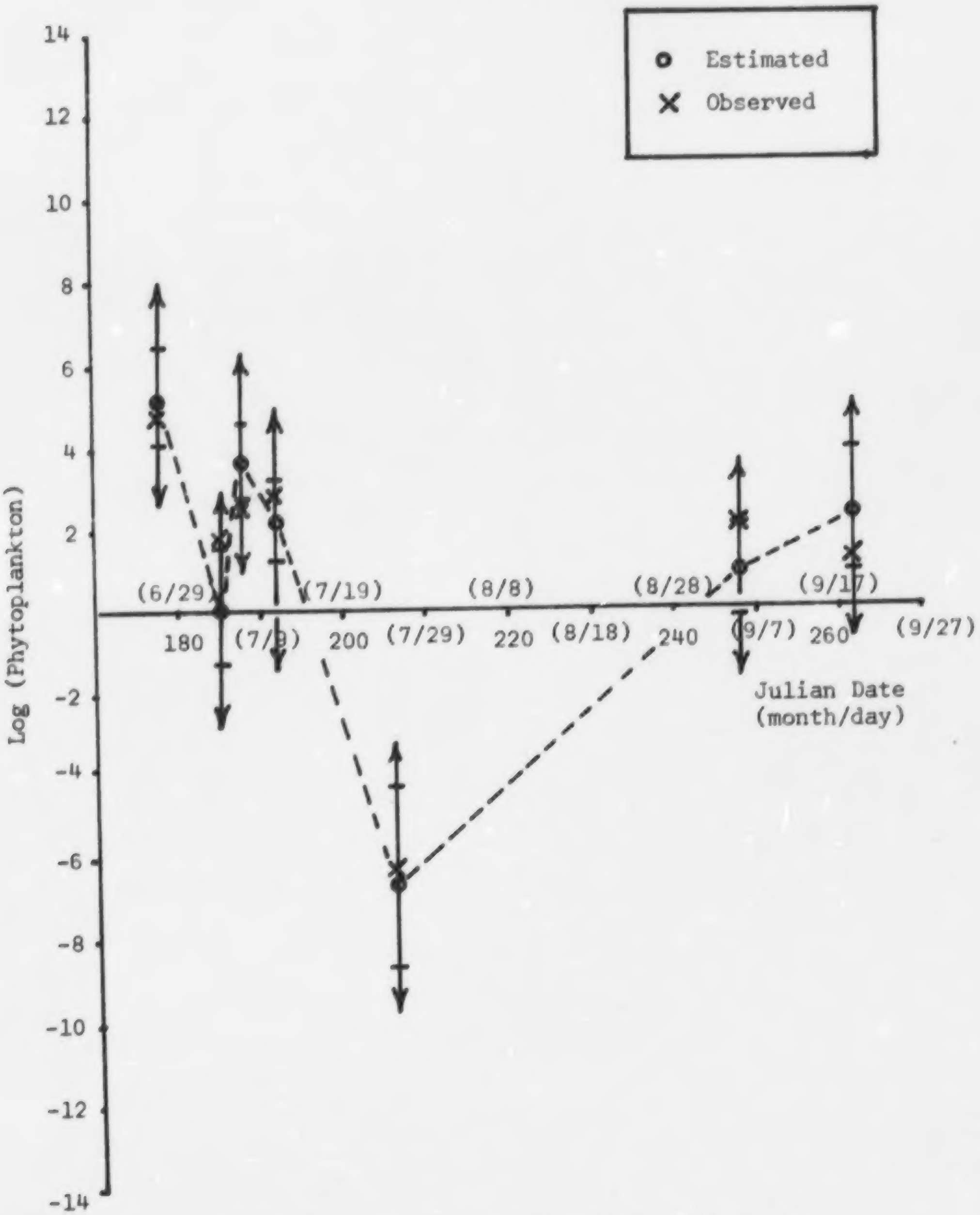

Figure 91 - Log(Phytoplankton) vs Julian Date
for Echo Bay, Station 1, Model 2

Model 2: Log(Phytoplankton) = 30.04 + 0.213(Bay) - 0.77(Station) + 0.22(Day) - 0.744(Temp) + 6.43(Surface Microorganisms) - 2.035(D.O.)

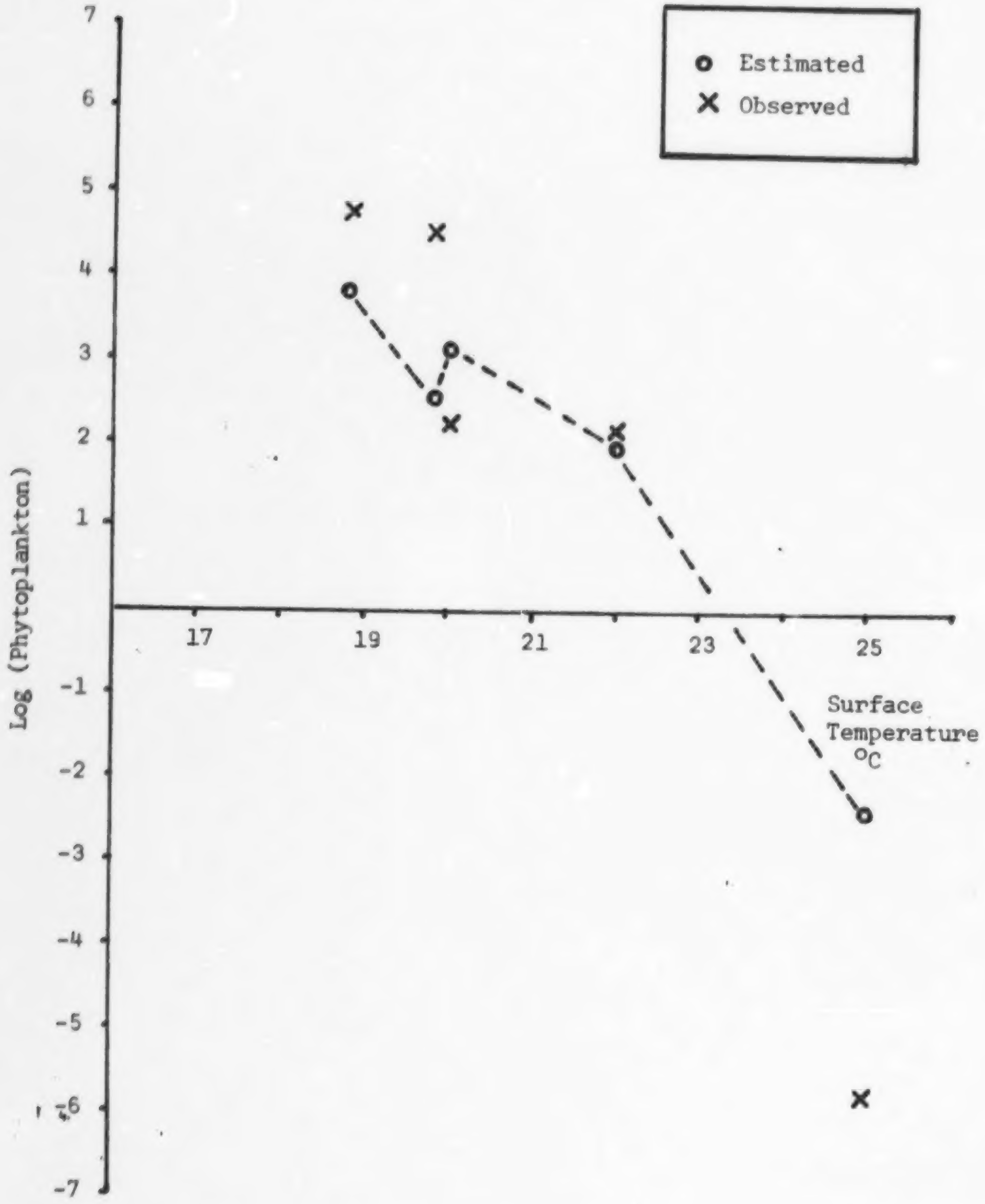

Figure 92 - Log(Phytoplankton) vs Surface Temperature for Echo Bay, Station 2, Model 2

Model 2: Log(Phytoplankton) = 30.04 + 0.213(Bay) - 0.77(Station) + 0.22(Day) - 0.744(Temp) + 6.43(Surface Microorganisms) - 2.035(D.O.)

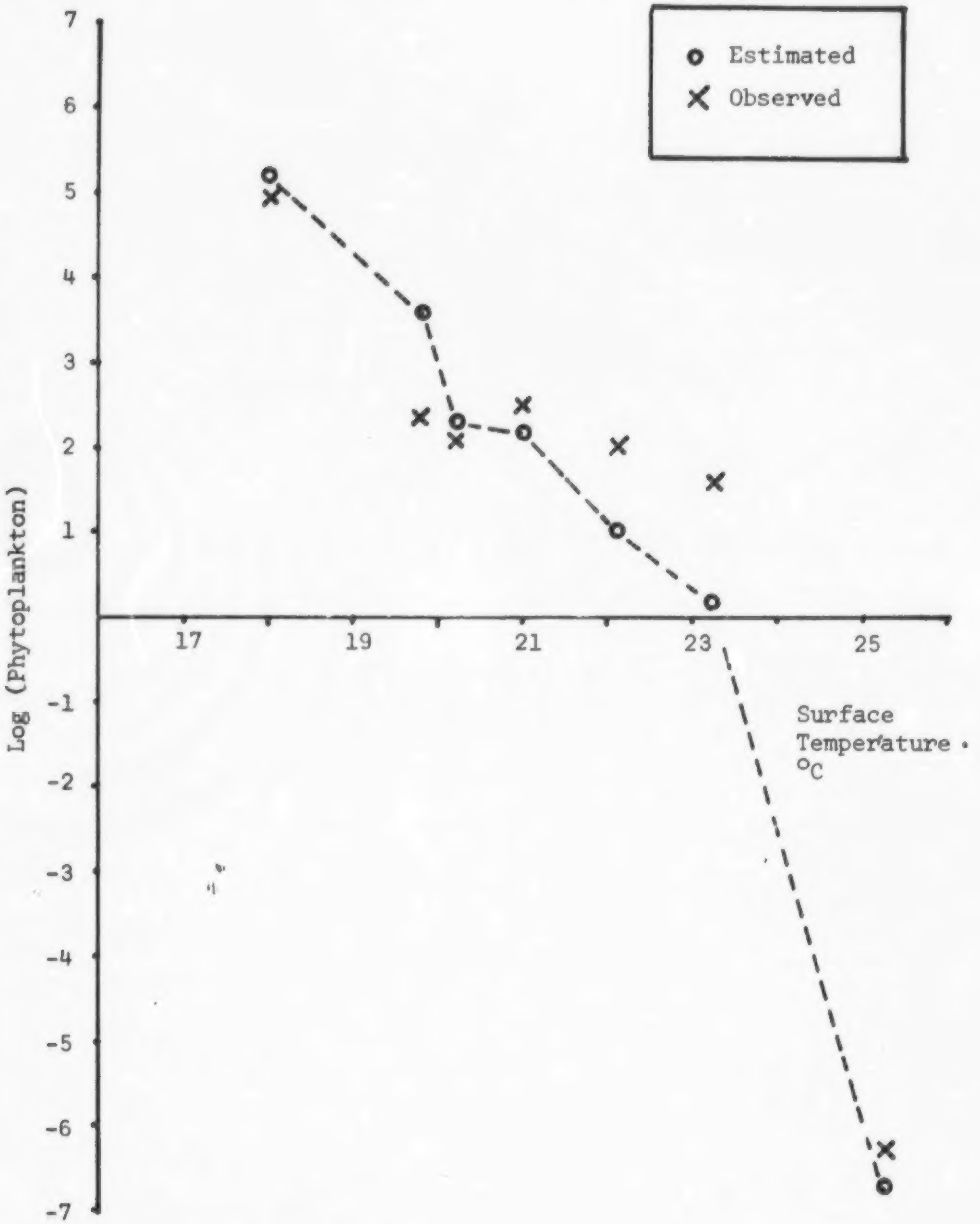

Figure 93 - Log(Phytoplankton) vs Surface Temperature for Echo Bay, Station 1, Model 2

Model 2: Log(Phytoplankton) = 30.04 + 0.213(Bay) - 0.77(Station)
+ 0.22(Day) - 0.744(Temp) + 6.43(Surface
Microorganisms) - 2.035(D.O.)

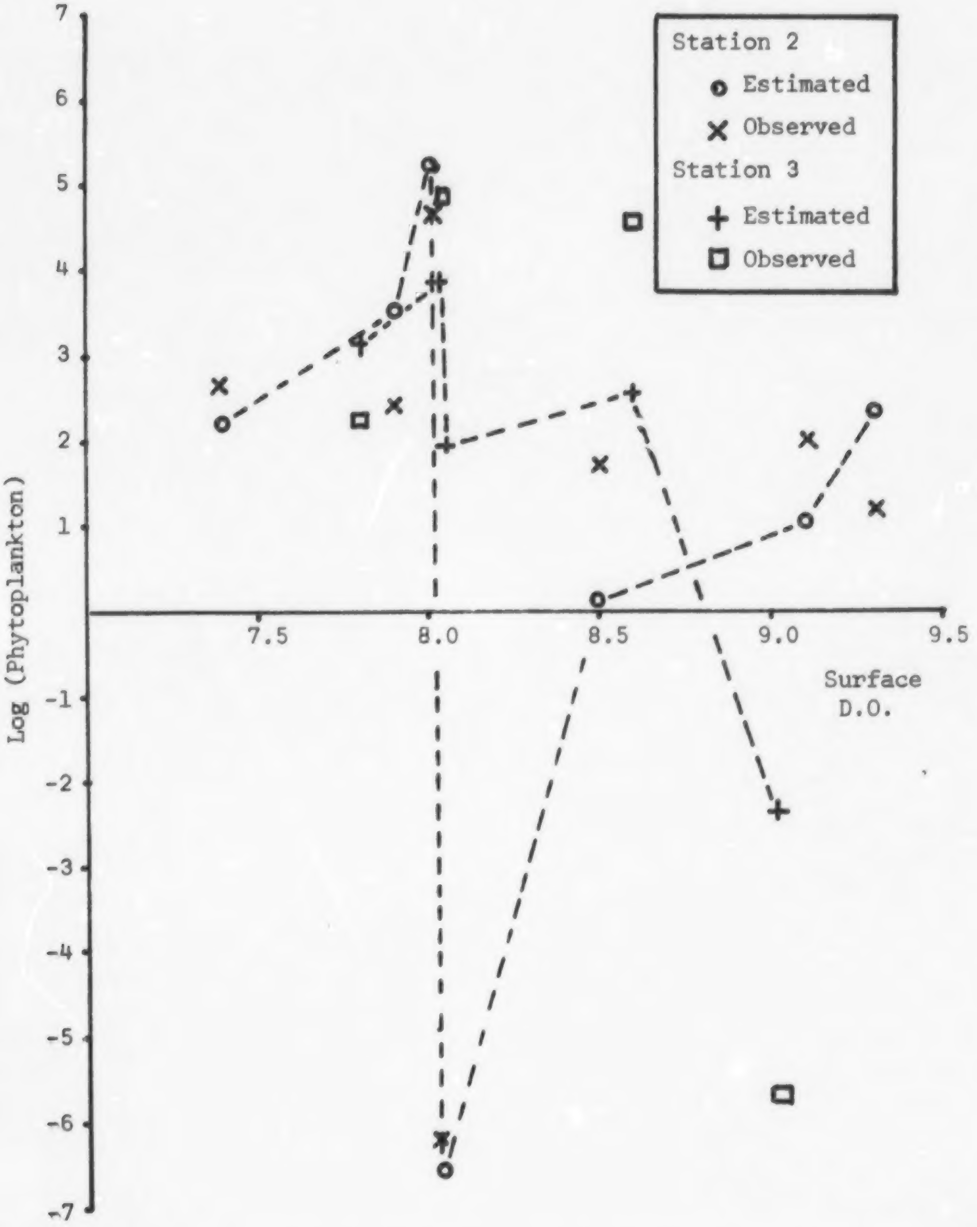

Figure 94 - Log(Phytoplankton) vs Dissolved Oxygen(Surface)
for Echo Bay, Stations 2 and 1, Model 2

Figures 90 & 91 are plots of the observed and estimated responses against Julian date for Echo Bay at Stations 2 and 3. As the plots indicate, the fit is reasonably good. However, it is worth re-emphasizing that even though the analysis gives a R^2 of 86%, the results are based on observations taken on only seven days. As the plots indicate, a few more observations must be taken around Julian date 200.

Confidence intervals and prediction intervals are indicated in Fig. 91.

RELATION BETWEEN COLUMN MICROORGANISMS, HYDROCARBON LEVEL, AND COLUMN TEMPERATURE

In this section the association between column microorganisms and hydrocarbon level, column temperature, square of column temperature (referred to as $(\text{temp})^2$ in the discussion below, i.e. temperature was accounted for using a quadratic function) and column dissolved oxygen is discussed.

Simultaneously observed data on the variables of interest are available on 17 days.

The over-all means and standard deviations for the different variables are given in Table 68a.

Table 68a

Over-All Means and Standard Deviations of Variables

Variable	Mean	Std. Dev.
Hydrocarbon Level	3.87	3.10
Column Temperature	19.47	4.08
$(\text{Temperature})^2$	395.58	131.95
Column Dissolved Oxygen	8.58	2.37
Column Microorganisms*	0.40	2.21

---

*natural logarithm of column microorganisms

The observations were taken at Echo Bay (25 observations) and Dunham Bay (33 observations).

The means and standard deviations at the two bays for the variables of interest are given in Tables 68b-68f.

Table 68b

Means and Standard Deviations of Hydrocarbon Level

	Echo Bay			Dunham Bay		
	Mean	Std. Dev.	N	Mean	Std. Dev.	N
STATION 3	--	--	--	3.19	1.60	10
STATION 2	4.00	2.5	12	3.07	1.66	10
STATION 1	3.9	1.6	13	4.9	5.62	13

Table 68c

Means and Standard Deviations of Temperature

	Echo Bay			Dunham Bay		
	Mean	Std. Dev.	N	Mean	Std. Dev.	N
STATION 3	--	--	--	16.78	5.28	10
STATION 2	20.57	2.44	12	17.37	5.24	10
STATION 1	21.36	2.05	13	20.26	3.51	13

Table 68d

Means and Standard Deviations of Dissolved Oxygen

	Echo Bay			Dunham Bay		
	Mean	Std. Dev.	N	Mean	Std. Dev.	N
STATION 3	--	--	--	8.4	1.9	10
STATION 2	8.77	0.89	12	9.95	3.54	10
STATION 1	8.38	0.88	13	7.65	3.24	13

Table 68e

Means and Standard Deviations of $(\text{Temperature})^2$

	Echo Bay			Dunham Bay		
	Mean	Std. Dev.	N	Mean	Std. Dev.	N
STATION 3	--	--	--	306.7	141.71	10
STATION 2	428.8	99.83	12	326.39	147.67	10
STATION 1	460.2	87.53	13	421.9	132.43	13

Table 68f

Means and Standard Deviations of Log (Column Microorganisms)

	Echo Bay			Dunham Bay		
	Mean	Std. Dev.	N	Mean	Std. Dev.	N
STATION 3	--	--	--	-1.15	1.21	10
STATION 2	0.96	2.29	12	-0.92	2.70	10
STATION 1	1.42	1.77	13	1.06	1.79	13

As in the case of phytoplankton, the column microorganisms were transformed by taking the natural logarithms. This is reasonable since the rate equation for growth of microorganisms is similar to that of the phytoplankton.

A total of 58 cases were considered in this study.

In Table 68g the results of the analysis are summarized.

Table 68g

Summary of Results

Variable	Coefficient	Std. Error	Increase in R^2%	F-value	Significance Level
(Constant)	-0.57	--	--	--	--
Day	0.023	0.010	19.91	5.110	0.05
Station	-0.713	0.350	10.33	4.160	0.05
Bay	-0.494	0.524	0.81	0.8870	--
Hydrocarbon	0.177	0.084	8.54	4.51	0.05
Temp.	-0.123	0.110	0.96	2.26	0.20*
D.O.	-0.417	0.280	0.10	1.25	0.30*
$(\text{Temp})^2$	0.013	0.008	2.54	2.23	0.20*

*approximate values

R^2 = 43.19; std. error of estimate = 3.149; degrees of freedom = 50

The F-values indicate that there might be associations between the Log (column microorganisms) and the other variables in the model. However, it should be noted that only 43% of the variation has been explained. This strongly indicates that the association of column microorganisms with other lake chemistry parameters, like NO_3, PO_4, surface water runoff, etc., might be worth investigating.

Figure 95 is a plot of the observed and estimated levels of Log (column microorganisms) against Julian date for Echo Bay. The value of 7.9 on the 22nd of August should be noted. On either side of this day, the level is below 2.3. This sudden increase may also be the reason for such a low R^2. This behavior around this date might be worth investigating.

Figure 96 is also a plot of Log (column microorganisms) against Julian date at Echo Bay for Station 1. Again, the high value on the 22nd of August should be noted.

Figure 95 also includes the prediction intervals and the confidence intervals for a few selected points.

RELATION BETWEEN SURFACE MICROORGANISMS, HYDROCARBON LEVEL, SURFACE DISSOLVED OXYGEN AND SURFACE TEMPERATURE

In this section the relationships between surface microorganisms and hydrocarbon, surface dissolved oxygen and surface temperature are analyzed.

Simultaneously observed data on the variables of interest were available on 14 days. The observations were taken at Echo Bay (22 observations) and Dunham Bay (29 observations).

The over-all means and standard deviations are given in Table 69a.

Table 69a

Over-All Means and Standard Deviations of Variables

Variable	Mean	Std. Dev.
Hydrocarbon Level	4.04	3.22
Surface Temperature	21.16	2.42
$(\text{Temperature})^2$	453.7	98.39
Surface Dissolved Oxygen	8.40	1.57
Surface Microorganisms	-2.07	2.03

In Tables 69b-69f the means and standard deviations of the unadjusted variables are given. Unadjusted data is raw data that has not been adjusted for Days.

Model 3: $\text{Log(Column Microorganisms)} = -0.57 - 0.494(\text{Bay}) - 0.713(\text{Station}) + 0.023(\text{Day}) + 0.177(\text{HC}) - 0.123(\text{Temp}) - 0.417(\text{D.O.}) + 0.013(\text{Temp})^2$

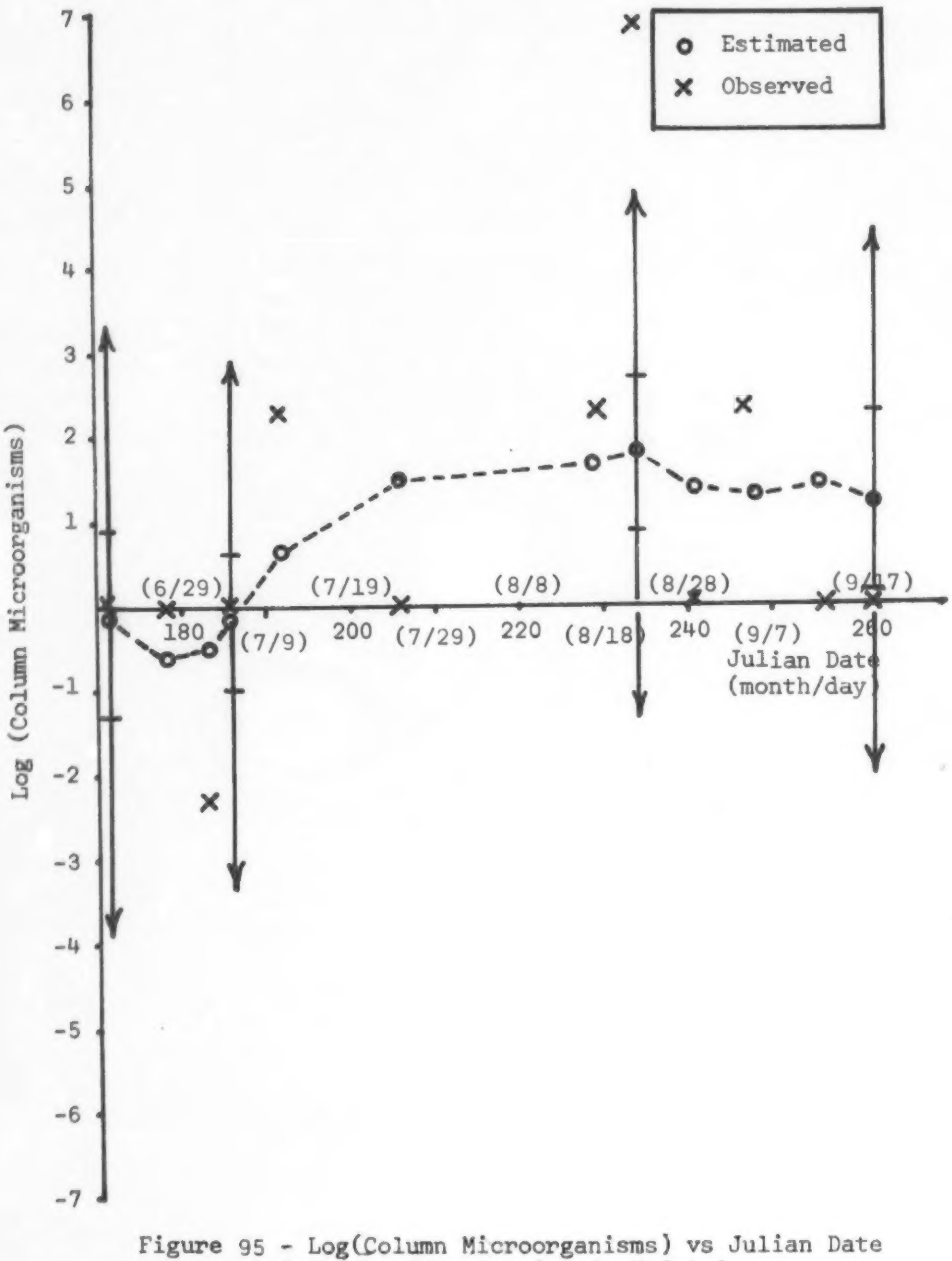

Figure 95 - Log(Column Microorganisms) vs Julian Date for Echo Bay, Station 2, Model 3

Model 3: Log(Column Microorganisms) = -0.57 - 0.494(Bay) -0.713(Station) + 0.023(Day) + 0.177(HC) -0.123(Temp) - 0.417(D.O.) + 0.013$(\text{Temp})^2$

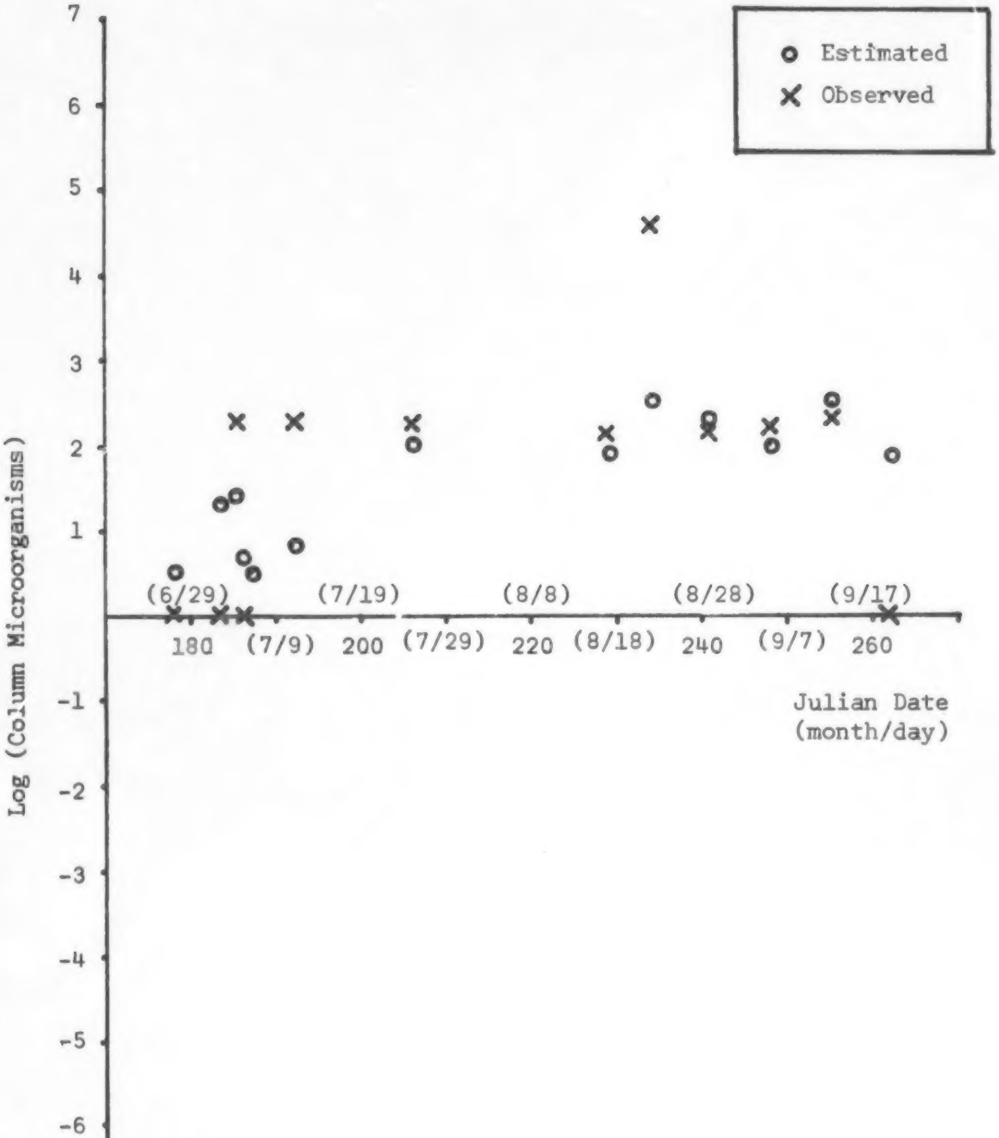

Figure 96 - Log(Column Microorganisms) vs Julian Date for Echo Bay, Station 1, Model 3

Table 69b

Means and Standard Deviations of Hydrocarbon Level

	Echo Bay			Dunham Bay		
	Mean	Std. Dev.	N	Mean	Std. Dev.	N
STATION 3	--	--	--	3.2	1.7	9
STATION 2	4.2	2.6	9	3.46	1.65	8
STATION 1	3.9	1.6	13	5.08	5.81	12

Table 69c

Means and Standard Deviations of Temperature

	Echo Bay			Dunham Bay		
	Mean	Std. Dev.	N	Mean	Std. Dev.	N
STATION 3	--	--	--	20.03	2.80	9
STATION 2	21.4	2.11	9	20.67	1.81	8
STATION 1	21.65	1.92	13	21.60	3.14	12

Table 69d

Means and Standard Deviations of Dissolved Oxygen

	Echo Bay			Dunham Bay		
	Mean	Std. Dev.	N	Mean	Std. Dev.	N
STATION 3	--	--	--	9.00	1.35	9
STATION 2	8.87	0.85	9	8.74	1.30	8
STATION 1	8.58	0.91	13	7.19	2.28	12

Table 69e

Means and Standard Deviations of Log (Surface Microorganisms)

	Echo Bay			Dunham Bay		
	Mean	Std. Dev.	N	Mean	Std. Dev.	N
STATION 3	--	--	--	-3.33	2.03	9
STATION 2	-2.81	1.54	9	-2.59	1.48	8
STATION 1	-1.69	1.67	13	-0.63	2.28	12

Table 69f

Means and Standard Deviations of $(Temperature)^2$

	Echo Bay			Dunham Bay		
	Mean	Std. Dev.	N	Mean	Std. Dev.	N
STATION 3	--	--	--	408.29	104.76	9
STATION 2	463.84	91.52	9	430.31	72.86	8
STATION 1	472.29	83.11	13	475.60	126.19	12

Again, the surface microorganisms were transformed using natural logarithm. Table 69g gives the summary of the results of this analysis.

Table 69g

Summary of Results

Variable	Coefficient	Std. Dev.	Increase in R^2%	F-value	Significance Level
(Constant)	-6.44	--	--	--	--
Station	0.82	0.55	18.87	2.23	0.15*
Bay	-1.19	0.36	3.37	10.84	0.01
Day	-0.004	0.01	0.36	0.14	--
$(Temp)^2$	0.20	0.12	4.26	2.68	0.15*

*approximate values

R^2 = 26.86; std. error of estimate = 1.8081; degrees of freedom = 46

After the response variable has been adjusted for temperature, the contribution due to hydrocarbon and dissolved oxygen is negligible. Most of the variability has been explained by the block variables.

RELATION BETWEEN ODOR, HYDROCARBON LEVEL, COLUMN MICROORGANISMS AND SURFACE MICROORGANISMS

In this section the association of logarithm of odor with hydrocarbon, column microorganisms and surface microorganisms and temperature are discussed.

Based on the reports of the investigators at Lake George, it was hypothesized that the odor level is associated with the phytoplankton level. However, there were simultaneous observations only on four days for a total of 8 points. Hence, it was decided not to attempt any analysis of the association between odor levels and phytoplankton. However, a plot of odor levels and phytoplankton levels against Julian date showed similar behavior.

The natural logarithm of the odor levels was used in the analysis. Observations of odor levels and hydrocarbon levels were available on 14 days.

The analysis is summarized in Table 70.

Table 70

Summary of Results

Variable	F-value
Bay	1.86
Station	1.10
Day	0.066
Hydrocarbon	0.07

As Table 70 indicates, there is no significant association between hydrocarbon level and the Log (odor).

SECTION XIV - ACKNOWLEDGEMENTS

Dr. William W. Shuster, Chairman of the Bio-Environmental Engineering Division at Rensselaer Polytechnic Institute, Troy, New York, served as Project Director of this investigation. The assistance of Dr. Lenore S. Clesceri, Assistant Professor of Biology, and Dr. Shigeru Kobayashi, Research Assistant, is gratefully acknowledged.

Valuable assistance with the microbiological studies was provided by Miss Rosalie Jennings and Miss Jeanne McGuire, graduate students in the Biology Department. Mr. Inder Jit Kumar assisted with the algae studies, and Mr. Peter Carney helped with engine tests and surface current measurements. Dr. James Basila provided assistance with the development of analytical procedures.

Dr. William Perrotte, Assistant Professor at Marist College, together with Mr. John Henningson, a graduate student at Rensselaer, assisted with the field measurements of benthal microorganisms and the surveys of boat usage.

The assistance of Mr. Michael Asbury, Mr. Francis Gregory and Mr. William Belden in sampling and with analytical work is acknowledged with thanks.

Inputs from Mr. Thomas Tough with odor tests, and from Mr. Miguel Antonetti with studies of bottom samples and the development of analytical methods were much appreciated.

Dr. John W. Wilkinson and Mr. K. Deva Kumar provided guidance in the statistical analysis of portions of the data.

The assistance and advice provided by Dr. Nicholas L. Clesceri and Dr. James J. Ferris were most valuable. The use of Rensselaer's Fresh Water Institute facilities was appreciated.

Support provided by the Water Quality Office, Environmental Protection Agency, and the help provided by Mr. Thomas H. Roush, Mr. Leo T. McCarthy, and Dr. Royal J. Nadeau, the Grant Project Officer, is acknowledged with thanks.

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SECTION XVI - APPENDICES

Page No.

A Computer Program for Calculating Maximum Specific Growth Rate for Algae 281

B Computer Output for Daily Absorbance Readings and Maximum Growth Rate for Algae 283

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C     * * * * * * * * * * * * * * * * * * * * * * * * *
C     *                                               *
C     *   RENSSELAER POLYTECHNIC INSTITUTE, TROY,N.Y.  *
C     *   BIO-ENVIRONMENTAL ENGINEERING DIVISION       *
C     *   MAXIMUM SPECIFIC GROWTH RATE DETERMINATION   *
C     *   BOTTLE TEST, EPA 1971                        *
C     *                                               *
C     * * * * * * * * * * * * * * * * * * * * * * * * *
C
      DIMENSION DAY(3,25),ABSORB(3,25),GR(3),RATE(3,25),IDAY(3)
      INTEGER TITLE(10)
      IN=5
      IO=6
      READ(IN,5)NPROB
    5 FORMAT(I3)
      DO 100 M=1,NPROB
      READ(IN,10)NCURVE,NDAY,TITLE
   10 FORMAT(2I2,2X,10A4)
      DO 20 I=1,NCURVE
      DO 25 J=1,NDAY
      READ(IN,40)DAY(I,J),ABSORB(I,J)
   40 FORMAT(5X,F2.0,F8.3)
   25 CONTINUE
   20 CONTINUE
      DA=0.0
      DO 50 I=1,NCURVE
      GR(I)=0.0
      DO 60 J=2,NDAY
      L=J-1
      RATE(I,J)=ALOG(ABSORB(I,J)/ABSORB(I,L))/(DAY(I,J)-DAY(I,L))
      IF (RATE(I,J).GT.GR(I)) IDAY(I)=J
      IF (RATE(I,J).GT.GR(I)) GR(I)=RATE(I,J)
   60 CONTINUE
      DA=DA+GR(I)
   50 CONTINUE
      AJSUM=0.0
      DMEAN=DA/NCURVE
      DO 70 I=1,NCURVE
      AJ=(DMEAN-GR(I))**2
      AJSUM=AJSUM+AJ
   70 CONTINUE
      SD=SQRT(AJSUM/NCURVE)
      WRITE(IO,80)TITLE
   80 FORMAT(1H1//49X,'RENSSELAER  POLYTECHNIC  INSTITUTE'/61X,'TROY,  N
     1.Y.'///42X,'DETERMINATION  OF  DAILY  AND  MAXIMUM  SPECIFIC'/41X,
     2'GROWTH  RATES  OF  ALGAL  CULTURES  (BOTTLE  TEST)'///24X,'SAMPLE
     3  TITLE   ',10A4//32X,'----------- ABSORBANCE -----------',5X,'--
     4----- DAILY GROWTH RATES -------'/24X,'DAY',5X,'BOTTLE 1',5X,'BOTT
     5LE 2',5X,'BOTTLE 3',5X,'BOTTLE 1',5X,'BOTTLE 2',5X,'BOTTLE 3'/)
      WRITE(IO,85)DAY(1,1),(ABSORB(I,1),I=1,NCURVE)
   85 FORMAT(24X,F3.0,(F11.3,2F13.3))
      DO 95 J=2,NDAY
      IF (NCURVE.EQ.3) GO TO 200
      IF (NCURVE.EQ.2) GO TO 202
      IF (NCURVE.EQ.1) GO TO 203
```

```
 200  WRITE(IO,90)(RATE(I,J),I=1,NCURVE),DAY(1,J),(ABSORB(I,J),I=1,NCURV
     1E)
  90  FORMAT(64X,(3F13.3)/24X,F3.0,(F11.3,2F13.3))
      GO TO 95
 202  WRITE(IO,91)(RATE(I,J),I=1,NCURVE),DAY(1,J),(ABSORB(I,J),I=1,NCURV
     1E)
  91  FORMAT(64X,(2F13.3)/24X,F3.0,(F11.3,F13.3))
      GO TO 95
 203  WRITE(IO,92)(RATE(I,J),I=1,NCURVE),DAY(1,J'),(ABSORB(I,J),I=1,NCURV
     1E)
  92  FORMAT(64X,(F13.3)/24X,F3.0,(F11.3))
      GO TO 95
  95  CONTINUE
      WRITE(IO,600)(IDAY(I),I=1,NCURVE)
 600  FORMAT(//43X,'DAY',16X,(3I13))
      WRITE(IO,110)(GR(I),I=1,NCURVE)
 110  FORMAT(/43X,'MAXIMUM  GROWTH  RATE',(3F13.3))
      WRITE(IO,120)GMEAN,SD
 120  FORMAT(/43X,'MEAN  MAXIMUM  GROWTH  RATE',F7.3//43X,'STANDARD  DEV
     1IATION  ',F12.3)
 100  CONTINUE
      WRITE(IO,800)
 800  FORMAT(1H1)
      STOP
      END

/DATA
```

```
                         RENSSELAER  POLYTECHNIC  INSTITUTE
                                   TROY,  N.Y.

                    DETERMINATION  OF  DAILY  AND  MAXIMUM  SPECIFIC
                    GROWTH  RATES  OF  ALGAL  CULTURES  (BOTTLE  TEST)

SAMPLES  TITLE     CAC609721JK

          ----------- ABSORBANCE -----------     ------- DAILY GROWTH RATES -------
DAY       BOTTLE 1     BOTTLE 2     BOTTLE 3     BOTTLE 1     BOTTLE 2     BOTTLE 3
  1.       0.015
  2.       0.030                                  0.693
  3.       0.062                                  0.726
  4.       0.140                                  0.815
  5.       0.245                                  0.560
  6.       0.442                                  0.590
  7.       0.580                                  0.272
  8.       0.625                                  0.075
  9.       0.695                                  0.106
 10.       0.765                                  0.096
 11.       0.885                                  0.146
 12.       0.905                                  0.022
 13.       0.920                                  0.016
 14.       0.940                                  0.022
 15.       0.915                                 -0.027

                  DAY                                4

                  MAXIMUM  GROWTH  RATE           0.815

                  MEAN  MAXIMUM  GROWTH  RATE     0.815

                  STANDARD  DEVIATION             0.000
```

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                    RENSSELAER  PCLYTECHNIC  INSTITUTE
                                TRCY,  N.Y.

               DETERMINATION  CF  DAILY  AND  MAXIMUM  SPECIFIC
              GRCWTH  RATES  CF  ALGAL  CULTURES  (BCTTLE  TEST)

SAMPLES  TITLE     1AC6097213K

          ------------ ABSCRBANCE -----------      ------- DAILY GRCWTH RATES -------
DAY      BOTTLE 1      BOTTLE 2      BCTTLE 3      BCTTLE 1     BOTTLE 2     BOTTLE 3

  1.      C.020         0.015
                                                    C.693        C.758
  2.      C.040         0.032
                                                    0.588        0.577
  3.      C.072         0.057
                                                    C.721        C.840
  4.      C.148         0.132
                                                    0.504        0.364
  5.      C.245         0.190
                                                    0.385        0.567
  6.      C.360         0.335
                                                    C.308        0.238
  7.      C.450         0.425
                                                    C.243        0.276
  8.      C.625         0.560
                                                    C.106        C.194
  9.      C.695         0.680
                                                    C.096        C.156
 10.      C.765         0.795
                                                    C.082        C.130
 11.      C.830         0.905
                                                    C.081       -C.006
 12.      C.900         0.900
                                                   -C.022        C.017
 13.      C.880         0.915
                                                    0.044        0.016
 14.      C.920         0.930
                                                   -C.022       -C.022
 15.      C.900         0.910

                        DAY                           4            4

                        MAXIMUM  GRCWTH  RATE       C.721        0.840

                        MEAN  MAXIMUM  GRCWTH  RATE C.780

                        STANDARD  DEVIATICN         C.060
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                                     TROY,  N.Y.

                   DETERMINATION  OF  DAILY  AND  MAXIMUM  SPECIFIC
                  GROWTH  RATES  OF  ALGAL  CULTURES  (BOTTLE  TEST)

SAMPLES  TITLE    5AC609721JK

         ------------ ABSORBANCE -----------       ------- DAILY GROWTH RATES -------
DAY      BOTTLE 1     BOTTLE 2     BOTTLE 3        BOTTLE 1    BOTTLE 2     BOTTLE 3

 1.      0.008        0.006        0.010
                                                   0.629       0.916        0.916
 2.      0.015        0.015        0.025
                                                   0.588       0.788        1.030
 3.      0.027        0.033        0.070
                                                   0.831       1.025        0.539
 4.      0.062        0.092        0.120
                                                   0.427       0.584        0.637
 5.      0.095        0.165        0.227
                                                   0.208       0.772        0.410
 6.      0.117        0.357        0.342
                                                   0.344       0.361        0.274
 7.      0.165        0.512        0.450
                                                   0.279       0.072        0.186
 8.      0.218        0.550        0.542
                                                   0.329       0.087        0.169
 9.      0.303        0.600        0.642
                                                   0.240       0.072        0.145
10.      0.385        0.645        0.742
                                                   0.320       0.157        0.100
11.      0.530        0.755        0.820
                                                   0.141       0.076        0.036
12.      0.610        0.815        0.850

                  DAY                                4           4            3

                  MAXIMUM  GROWTH  RATE            0.831       1.025        1.030

                  MEAN  MAXIMUM  GROWTH  RATE      0.962

                  STANDARD  DEVIATION              0.092
```

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                    RENSSELAER  POLYTECHNIC  INSTITUTE
                                 TROY,  N.Y.

              DETERMINATION  OF  DAILY  AND  MAXIMUM  SPECIFIC
              GROWTH  RATES  OF  ALGAL  CULTURES  (BOTTLE  TEST)

SAMPLES  TITLE    10AC609721JK

        ------------ ABSORBANCE ------------     ------- DAILY GROWTH RATES -------
DAY     BOTTLE 1      BOTTLE 2     BOTTLE 3     BOTTLE 1     BOTTLE 2     BOTTLE 3

 1.      0.011         0.008
                                                 0.435        0.405
 2.      0.017         0.012
                                                 0.386        0.693
 3.      0.025         0.024
                                                 0.419        0.734
 4.      0.038         0.050
                                                 0.490        0.470
 5.      0.062         0.080
                                                 0.405        0.765
 6.      0.093         0.172
                                                 0.478        0.421
 7.      0.150         0.262
                                                 0.511        0.563
 8.      0.250         0.460
                                                 0.392        0.132
 9.      0.370         0.525
                                                 0.281        0.117
10.      0.490         0.590
                                                 0.275        0.185
11.      0.645         0.710
                                                 0.038        0.041
12.      0.670         0.740
                                                 0.072        0.065
13.      0.720         0.790
                                                 0.027        0.073
14.      0.740         0.850
                                                 0.020       -0.024
15.      0.755         0.830

                    DAY                            8            6

                    MAXIMUM  GROWTH  RATE        0.511        0.765

                    MEAN  MAXIMUM  GROWTH  RATE  0.638

                    STANDARD  DEVIATION          0.127
                    RENSSELAER  POLYTECHNIC  INSTITUTE
                                 TROY,  N.Y.

                 DETERMINATION  OF  DAILY  AND  MAXIMUM  SPECIFIC
                GROWTH  RATES  OF  ALGAL  CULTURES  (BOTTLE  TEST)

SAMPLES  TITLE   20AC60972IJK

        ----------- ABSORBANCE -----------     ------- DAILY GROWTH RATES -------
DAY     BOTTLE 1    BOTTLE 2     BOTTLE 3      BOTTLE 1     BOTTLE 2     BOTTLE 3

 1.      0.002       0.002
                                                 0.405        0.405
 2.      0.003       0.003
                                                 0.288        0.511
 3.      0.004       0.005
                                                 0.223        0.470
 4.      0.005       0.008
                                                 0.182        0.223
 5.      0.006       0.010
                                                 0.288        0.182
 6.      0.008       0.012
                                                 0.223        0.405
 7.      0.010       0.018
                                                 0.405        0.575
 8.      0.015       0.032
                                                 0.288        0.384
 9.      0.020       0.047
                                                 0.300        0.277
10.      0.027       0.062
                                                 0.831        0.373
11.      0.062       0.090
                                                 0.047       -0.057
12.      0.065       0.085
                                                 0.613        0.386
13.      0.120       0.125
                                                 0.536        0.336
14.      0.205       0.175
                                                 0.257        0.182
15.      0.265       0.210

                    DAY                            11            8

                    MAXIMUM  GROWTH  RATE        0.831        0.575

                    MEAN  MAXIMUM  GROWTH  RATE  0.703

                    STANDARD  DEVIATION          0.128
                    RENSSELAER  PCLYTECHNIC  INSTITUTE
                                TRCY, N.Y.

             DETERMINATION  CF  CAILY  AND  MAXIMUM  SPECIFIC
             GROWTH  RATES  CF  ALGAL  CULTURES  (BOTTLE  TEST)

SAMPLES  TITLE   30AC609721JK

        ----------- ABSORBANCE -----------     ------- CAILY GROWTH RATES -------
DAY     BOTTLE 1     BOTTLE 2     BOTTLE 3     BCTTLE 1     BOTTLE 2     BOTTLE 3

 1.      0.002        0.002
                                                0.405        0.405
 2.      0.003        0.003
                                                0.511        0.000
 3.      0.005        0.003
                                                0.470       -0.405
 4.      0.008        0.002
                                                0.223        0.405
 5.      0.010        0.003
                                                0.693        0.000
 6.      0.020        0.003
                                                0.693       -0.405
 7.      0.040        0.002
                                                0.718        0.405
 8.      0.082        0.003
                                                0.797        0.511
 9.      0.182        0.005
                                                0.402        0.470
10.      0.272        0.008
                                                0.578        0.629
11.      0.485        0.015
                                                0.070       -0.405
12.      0.520        0.010
                                                0.019        0.642
13.      0.530        0.019
                                                0.055        0.666
14.      0.560        0.037
                                                0.035        0.693
15.      0.580        0.074
                                                0.075        0.638
16.      0.625        0.140
                                                0.039        0.619
17.      0.650        0.260
                                                0.038        0.480
18.      0.675        0.420

                     DAY                          9           15

                     MAXIMUM  GROWTH  RATE      0.797        0.693

                     MEAN  MAXIMUM  GROWTH  RATE  0.745

                     STANDARD  DEVIATION        0.052
                     RENSSELAER  POLYTECHNIC  INSTITUTE
                                TROY, N.Y.

              DETERMINATION  OF  DAILY  AND  MAXIMUM  SPECIFIC
              GROWTH  RATES  OF  ALGAL  CULTURES  (BOTTLE  TEST)

SAMPLES  TITLE   60AC609721JK

      ----------- ABSORBANCE -----------       ------- DAILY GROWTH RATES -------
DAY    BOTTLE 1      BOTTLE 2      BOTTLE 3      BOTTLE 1    BOTTLE 2     BOTTLE 3
 1.     0.009         0.004         0.003
 2.     0.009         0.003         0.002         0.000      -0.288       -0.405
 3.     0.010         0.005         0.004         0.105       0.511        0.693
 4.     0.013         0.010         0.008         0.262       0.693        0.693
 5.     0.010         0.018         0.008        -0.262       0.588        0.000
 6.     0.016         0.035         0.016         0.470       0.665        0.693
 7.     0.010         0.075         0.035        -0.470       0.762        0.783
 8.     0.010         0.165         0.080         0.000       0.788        0.827
 9.     0.020         0.305         0.160         0.693       0.614        0.693
10.     0.041         0.422         0.234         0.718       0.325        0.380
11.     0.095         0.460         0.422         0.840       0.086        0.590
12.     0.112         0.440         0.465         0.165      -0.044        0.097
13.     0.288         0.585         0.525         0.944       0.285        0.121
14.     0.405         0.660         0.615         0.341       0.121        0.158
15.     0.500         0.710         0.635         0.211       0.073        0.032

                DAY                             13          8            8

                MAXIMUM  GROWTH  RATE           0.944       0.788        0.827

                MEAN  MAXIMUM  GROWTH  RATE     0.853

                STANDARD  DEVIATION             0.066
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                           TROY,  N.Y.

          DETERMINATION  OF  DAILY  AND  MAXIMUM  SPECIFIC
          GROWTH  RATES  OF  ALGAL  CULTURES  (BOTTLE  TEST)

SAMPLES  TITLE     0R0515721JK

        ----------- ABSORBANCE -----------    ------- DAILY GROWTH RATES -------
DAY     BOTTLE 1     BOTTLE 2     BOTTLE 3    BOTTLE 1    BOTTLE 2    BOTTLE 3
 1.      0.113        0.232        0.172       0.214       0.274       0.232
 2.      0.140        0.305        0.217       0.700       0.595       0.515
 3.      0.282        0.553        0.363       0.362       0.344       0.359
 4.      0.455        0.780        0.520       0.359       0.187       0.238
 5.      0.580        0.940        0.650       0.244       0.130       0.180
 6.      0.740        1.070        0.770       0.105       0.055       0.119
 7.      [illegible]  1.130        0.890       0.045       0.068       0.076
 8.      0.860        1.210        0.960       0.171       0.024       0.026
 9.      1.020        1.240        0.985       0.048       0.047       0.064
10.      1.070        1.300        1.050       0.028       0.008       0.028
11.      1.100        1.310        1.080       0.027       0.000       0.018
12.      1.130        1.310        1.100       0.026       0.004       0.018
13.      1.150        1.315        1.120       0.034       0.004       0.026
14.      1.200        1.320        1.150       0.017       0.008       0.026
15.      1.220        1.330        1.180       0.016       0.015       0.017
16.      1.240        1.350        1.235       0.008       0.007       0.041
17.      1.250        1.360        1.250       0.016       0.007       0.024
18.      1.270        1.370        1.280

                 DAY                               3           3           3

                 MAXIMUM  GROWTH  RATE           0.700       0.595       0.515

                 MEAN  MAXIMUM  GROWTH  RATE     0.603

                 STANDARD  DEVIATION             0.076
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                  DETERMINATION  OF  DAILY  AND  MAXIMUM  SPECIFIC
                  GROWTH  RATES  OF  ALGAL  CULTURES  (BOTTLE  TEST)

SAMPLES  TITLE     1R0515721JK

         ----------- ABSORBANCE -----------     ------- DAILY GROWTH RATES -------
DAY      BOTTLE 1     BOTTLE 2     BOTTLE 3     BOTTLE 1     BOTTLE 2     BOTTLE 3

 1.      0.202        0.216
                                                0.372        0.223
 2.      0.293        0.270
                                                0.679        0.688
 3.      0.578        0.537
                                                0.374        0.360
 4.      0.840        0.770
                                                0.184        0.183
 5.      1.010        0.925
                                                0.121        0.127
 6.      1.140        1.050
                                                0.034        0.073
 7.      1.180        1.130
                                                0.058        0.052
 8.      1.250        1.190
                                                0.031        0.008
 9.      1.290        1.200
                                                0.015        0.049
10.      1.310        1.260
                                                0.000        0.008
11.      1.310        1.270
                                                0.000        0.000
12.      1.310        1.270
                                                0.004        0.008
13.      1.315        1.280
                                                0.004        0.016
14.      1.320        1.300
                                                0.008        0.015
15.      1.330        1.320
                                                0.007        0.015
16.      1.340        1.340
                                                0.007        0.007
17.      1.350        1.350
                                                0.015        0.007
18.      1.370        1.360

                      DAY                       3            3

                      MAXIMUM  GROWTH  RATE     0.679        0.688

                      MEAN  MAXIMUM  GROWTH  RATE  0.683

                      STANDARD  DEVIATION       0.004
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DETERMINATION OF DAILY AND MAXIMUM SPECIFIC
GROWTH RATES OF ALGAL CULTURES (BOTTLE TEST)

SAMPLES TITLE 5M051572IJK

	ABSORBANCE			DAILY GROWTH RATES		
DAY	BOTTLE 1	BOTTLE 2	BOTTLE 3	BOTTLE 1	BOTTLE 2	BOTTLE 3
1.	0.214	0.202		0.287	0.153	
2.	0.265	0.245		0.532	0.520	
3.	0.485	0.412		0.345	0.298	
4.	0.685	0.555		0.216	0.173	
5.	0.850	0.660		0.127	0.141	
6.	0.965	0.760		0.075	0.112	
7.	1.040	0.850		0.028	0.097	
8.	1.070	0.937		0.019	0.024	
9.	1.090	0.960		0.071	0.070	
10.	1.170	1.030		0.009	0.029	
11.	1.180	1.060		0.017	0.028	
12.	1.200	1.090		0.008	0.009	
13.	1.210	1.100		0.008	0.009	
14.	1.220	1.110		0.016	0.027	
15.	1.240	1.140		0.008	0.026	
16.	1.250	1.170		0.024	0.025	
17.	1.280	1.200		0.016	0.033	
18.	1.300	1.240				

DAY	3	3
MAXIMUM GROWTH RATE	0.532	0.520
MEAN MAXIMUM GROWTH RATE	0.526	
STANDARD DEVIATION	0.006	

RENSSELAER POLYTECHNIC INSTITUTE
TROY, N.Y.

DETERMINATION OF DAILY AND MAXIMUM SPECIFIC
GROWTH RATES OF ALGAL CULTURES (BOTTLE TEST)

SAMPLES TITLE 10M0515721JK

	ABSORBANCE			DAILY GROWTH RATES		
DAY	BOTTLE 1	BOTTLE 2	BOTTLE 3	BOTTLE 1	BOTTLE 2	BOTTLE 3
1.	0.245	0.205	0.182			
2.	0.327	0.270	0.217	0.289	0.275	0.176
3.	0.493	0.393	0.338	0.411	0.375	0.443
4.	0.650	0.525	0.440	0.276	0.290	0.264
5.	0.755	0.640	0.550	0.150	0.198	0.223
6.	0.880	0.745	0.658	0.153	0.152	0.179
7.	0.940	0.810	0.730	0.066	0.084	0.104
8.	0.990	0.880	0.810	0.052	0.083	0.104
9.	1.020	0.920	0.835	0.030	0.044	0.030
10.	1.070	0.970	0.900	0.048	0.053	0.075
11.	1.090	1.020	0.945	0.019	0.050	0.049
12.	1.100	1.040	0.975	0.009	0.019	0.031
13.	1.120	1.050	1.010	0.018	0.010	0.035
14.	1.130	1.070	1.050	0.009	0.019	0.039
15.	1.160	1.110	1.080	0.026	0.037	0.028
16.	1.200	1.140	1.120	0.034	0.027	0.036
17.	1.230	1.160	1.140	0.025	0.017	0.018
18.	1.260	1.180	1.160	0.024	0.017	0.017

DAY	3	3	3
MAXIMUM GROWTH RATE	0.411	0.375	0.443
MEAN MAXIMUM GROWTH RATE	0.410		
STANDARD DEVIATION	0.028		

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                 DETERMINATION  OF  DAILY  AND  MAXIMUM  SPECIFIC
                 GROWTH  RATES  OF  ALGAL  CULTURES  (BOTTLE  TEST)

SAMPLES  TITLE     20W0515721JK

        ------------ ABSORBANCE ------------    ------- DAILY GROWTH RATES -------
DAY     BOTTLE 1     BOTTLE 2     BOTTLE 3      BOTTLE 1    BOTTLE 2    BOTTLE 3

 1.      0.170        0.150        0.215
                                                  0.158       0.365       0.135
 2.      0.199        0.216        0.246
                                                  0.427       0.663       0.381
 3.      0.305        0.419        0.360
                                                  0.246       0.408       0.245
 4.      0.390        0.630        0.460
                                                  0.248       0.251       0.197
 5.      0.500        0.810        0.560
                                                  0.215       0.175       0.157
 6.      0.620        0.965        0.655
                                                  0.143       0.075       0.115
 7.      0.715        1.040        0.735
                                                  0.087       0.047       0.116
 8.      0.780        1.090        0.825
                                                  0.080       0.027       0.042
 9.      0.845        1.120        0.860
                                                  0.096       0.069       0.045
10.      0.930        1.200        0.900
                                                  0.047       0.008       0.043
11.      0.975        1.210        0.940
                                                  0.035       0.000       0.037
12.      1.010        1.210        0.975
                                                  0.039       0.008       0.035
13.      1.050        1.220        1.010
                                                  0.037       0.008       0.029
14.      1.090        1.230        1.040
                                                  0.027       0.008       0.019
15.      1.120        1.240        1.060
                                                  0.026       0.016       0.028
16.      1.150        1.260        1.090
                                                  0.017       0.016       0.009
17.      1.170        1.280        1.100
                                                  0.017       0.016       0.018
18.      1.190        1.300        1.120

                 DAY                              3           3           3

                 MAXIMUM  GROWTH  RATE            0.427       0.663       0.381

                 MEAN  MAXIMUM  GROWTH  RATE      0.490

                 STANDARD  DEVIATION              0.123
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RENSSELAER POLYTECHNIC INSTITUTE
TROY, N.Y.

DETERMINATION OF DAILY AND MAXIMUM SPECIFIC
GROWTH RATES OF ALGAL CULTURES (BOTTLE TEST)

SAMPLES TITLE 35M051572IJK

	ABSORBANCE			DAILY GROWTH RATES		
DAY	BOTTLE 1	BOTTLE 2	BOTTLE 3	BOTTLE 1	BOTTLE 2	BOTTLE 3
1.	0.142	0.195	0.180			
2.	0.196	0.293	0.265	0.322	0.407	0.387
3.	0.322	0.488	0.445	0.496	0.510	0.518
4.	0.410	0.655	0.625	0.242	0.294	0.340
5.	0.515	0.800	0.775	0.228	0.200	0.215
6.	0.625	0.930	0.910	0.194	0.151	0.161
7.	0.700	1.010	0.990	0.113	0.083	0.084
8.	0.780	1.070	1.060	0.108	0.058	0.068
9.	0.810	1.080	1.080	0.038	0.009	0.019
10.	[illegible]	1.140	1.140	0.066	0.054	0.054
11.	0.915	1.160	1.160	0.056	0.017	0.017
12.	0.945	1.180	1.180	0.032	0.017	0.017
13.	0.970	1.200	1.210	0.026	0.017	0.025
14.	1.000	1.210	1.230	0.030	0.008	0.016
15.	1.040	1.240	1.250	0.039	0.024	0.016
16.	1.080	1.270	1.270	0.038	0.024	0.016
17.	1.100	1.290	1.290	0.018	0.016	0.016
18.	1.120	1.310	1.310	0.018	0.015	0.015

	BOTTLE 1	BOTTLE 2	BOTTLE 3
DAY	3	3	3
MAXIMUM GROWTH RATE	0.496	0.510	0.518
MEAN MAXIMUM GROWTH RATE	0.508		
STANDARD DEVIATION	0.009		

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                      DETERMINATION  OF  DAILY  AND  MAXIMUM  SPECIFIC
                      GROWTH  RATES  CF  ALGAL  CULTURES  (BOTTLE  TEST)

SAMPLES  TITLE   120M0515721JK

            ----------- ABSORBANCE -----------        ------- DAILY GROWTH RATES -------
DAY        BOTTLE 1      BOTTLE 2      BOTTLE 3      BCTTLE 1      BOTTLE 2      BOTTLE 3

 1.         C.072         0.060
                                                      0.189         0.080
 2.         C.087         0.065
                                                      0.545         0.480
 3.         0.150         0.105
                                                      0.462         0.376
 4.         C.238         0.153
                                                      0.561         0.639
 5.         0.417         0.290
                                                      0.389         0.428
 6.         C.615         0.445
                                                      0.341         0.439
 7.         0.865         0.690
                                                      0.203         0.304
 8.         1.060         0.935
                                                      C.037         0.116
 9.         1.100         1.050
                                                      C.079         0.073
10.         1.190         1.130
                                                      0.008         0.052
11.         1.200         1.190
                                                      0.017         0.008
12.         1.220         1.200
                                                      0.016         0.008
13.         1.240         1.210
                                                      C.016         0.008
14.         1.260         1.220
                                                      0.016         0.024
15.         1.280         1.250
                                                      0.008         0.024
16.         1.290         1.280
                                                      C.008         0.016
17.         1.300         1.300
                                                      0.008         0.015
18.         1.310         1.320

                          DAY                           5             5

                          MAXIMUM  GROWTH  RATE         0.561         0.639

                          MEAN · MAXIMUM  GRCWTH  RATE  0.600

                          STANDARD  DEVIATICN           0.039
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                                  TROY,  N.Y.

                    DETERMINATION  OF  DAILY  AND  MAXIMUM  SPECIFIC
                    GROWTH  RATES  OF  ALGAL  CULTURES  (BOTTLE  TEST)

SAMPLES  TITLE    0S051572IJK

          ----------- ABSORBANC -----------     ------- DAILY GROWTH RATES -------
DAY     BOTTLE 1     BOTTLE 2     BOTTLE 3     BOTTLE 1     BOTTLE 2     BOTTLE 3

 1.      0.060        0.075        0.090
                                                 0.651        1.006        0.981
 2.      0.115        0.205        0.240
                                                 0.835        1.146        1.099
 3.      0.265        0.645        0.720
                                                 0.507        0.408        0.318
 4.      0.440        0.970        0.990
                                                 0.186        0.144        0.078
 5.      0.530        1.120        1.070
                                                 0.107        0.077        0.063
 6.      0.590        1.210        1.140
                                                 0.081        0.056        0.043
 7.      0.640        1.280        1.190
                                                 0.031        0.031        0.041
 8.      0.660        1.320        1.240
                                                 0.094       -0.023        0.000
 9.      0.725        1.290        1.240
                                                 0.000        0.045        0.024
10.      0.725        1.350        1.270
                                                 0.105        0.007        0.008
11.      0.805        1.360        1.280
                                                 0.037        0.007        0.008
12.      0.835        1.370        1.290
                                                 0.035        0.014        0.008
13.      0.865        1.390        1.300
                                                 0.034        0.007        0.008
14.      0.895        1.400        1.310
                                                 0.033        0.007        0.000
15.      0.925        1.410        1.310
                                                 0.032        0.007        0.008
16.      0.955        1.420        1.320
                                                 0.016        0.014        0.022
17.      0.970        1.440        1.350
                                                 0.015        0.014        0.015
18.      0.985        1.460        1.370

                    DAY                          3            3            3

                    MAXIMUM  GROWTH  RATE        0.835        1.146        1.099

                    MEAN  MAXIMUM  GROWTH  RATE  1.027

                    STANDARD  DEVIATION          0.137
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                 DETERMINATION  OF  DAILY  AND  MAXIMUM  SPECIFIC
                 GROWTH  RATES  OF  ALGAL  CULTURES  (BOTTLE  TEST)

SAMPLES  TITLE   1S051572IJK

       ----------- ABSORBANCE -----------      ------- DAILY GROWTH RATES -------
DAY    BOTTLE 1     BOTTLE 2     BOTTLE 3      BOTTLE 1     BOTTLE 2     BOTTLE 3

 1.     0.140        0.085        0.145
                                                0.429        0.830        0.565
 2.     0.215        0.195        0.255
                                                0.366        1.204        0.703
 3.     0.310        0.650        0.515
                                                0.517        0.400        0.507
 4.     0.520        0.970        0.855
                                                0.405        0.126        0.243
 5.     0.780        1.100        1.090
                                                0.248        0.070        0.153
 6.     1.000        1.180        1.270
                                                0.140        0.033        0.061
 7.     1.150        1.220        1.350
                                                0.067        0.016        0.015
 8.     1.230        1.240        1.370
                                                0.048        0.032       -0.015
 9.     1.290        1.280        1.350
                                                0.000        0.000        0.036
10.     1.290        1.280        1.400
                                                0.015        0.008        0.007
11.     1.310        1.290        1.410
                                                0.015        0.008        0.007
12.     1.330        1.300        1.420
                                                0.015        0.015        0.007
13.     1.350        1.320        1.430
                                                0.015        0.015        0.007
14.     1.370        1.340        1.440
                                                0.007        0.007        0.000
15.     1.380        1.350        1.440
                                                0.007        0.000        0.000
16.     1.390        1.350        1.440
                                                0.007        0.000        0.007
17.     1.400        1.350        1.450
                                                0.014        0.007        0.007
18.     1.420        1.360        1.460

                     DAY                          4            3            3

                     MAXIMUM  GROWTH  RATE        0.517        1.204        0.703

                     MEAN  MAXIMUM  GROWTH  RATE  0.808

                     STANDARD  DEVIATION          0.290
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                    RENSSELAER  POLYTECHNIC  INSTITUTE
                               TROY,  N.Y.

              DETERMINATION  OF  DAILY  AND  MAXIMUM  SPECIFIC
             GROWTH  RATES  OF  ALGAL  CULTURES  (BOTTLE  TEST)

SAMPLES  TITLE   5505157211JK

      ----------- ABSORBANCE -----------    ------- DAILY GROWTH RATES -------
DAY   BOTTLE 1    BOTTLE 2    BOTTLE 3     BOTTLE 1    BOTTLE 2    BOTTLE 3

 1.    0.080       0.105       0.095
                                             0.916       0.981       0.840
 2.    0.200       0.280       0.220
                                             1.099       0.857       0.925
 3.    0.600       0.660       0.555
                                             0.336       0.354       0.390
 4.    0.840       0.940       0.820
                                             0.159       0.120       0.188
 5.    0.985       1.060       0.990
                                             0.146       0.073       0.123
 6.    1.140       1.140       1.120
                                             0.034       0.051       0.035
 7.    1.180       1.200       1.160
                                             0.017       0.017       0.042
 8.    1.200       1.220       1.210
                                             0.033       0.024       0.033
 9.    1.240       1.250       1.250
                                             0.008       0.008       0.008
10.    1.250       1.260       1.260
                                             0.008       0.008       0.016
11.    1.260       1.270       1.280
                                             0.008       0.016       0.008
12.    1.270       1.290       1.290
                                             0.016       0.008       0.015
13.    1.290       1.300       1.310
                                             0.015       0.015       0.015
14.    1.310       1.320       1.330
                                             0.000       0.000       0.000
15.    1.310       1.320       1.330
                                            -0.008      -0.008      -0.015
16.    1.300       1.310       1.310
                                             0.008       0.015       0.015
17.    1.310       1.330       1.330
                                             0.008       0.007       0.015
18.    1.320       1.340       1.350

             DAY                               3           2           3

             MAXIMUM  GROWTH  RATE           1.099       0.981       0.925

             MEAN  MAXIMUM  GROWTH  RATE   1.002

             STANDARD  DEVIATION             0.072
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                    RENSSELAER  POLYTECHNIC  INSTITUTE
                              TROY,  N.Y.

              DETERMINATION  OF  DAILY  AND  MAXIMUM  SPECIFIC
              GROWTH  RATES  OF  ALGAL  CULTURES  (BOTTLE  TEST)

SAMPLES  TITLE   10S0515721JK

       ----------- ABSORBANCE -----------     ------- DAILY GROWTH RATES -------
DAY    BOTTLE 1     BOTTLE 2     BOTTLE 3     BOTTLE 1    BOTTLE 2    BOTTLE 3

 1.     0.050        0.050        0.080
                                                1.051       0.673       0.589
 2.     0.143        0.098        0.215
                                                1.101       0.976       1.209
 3.     0.430        0.260        0.720
                                                0.416       0.654       0.358
 4.     0.652        0.500        1.030
                                                0.241       0.378       0.110
 5.     0.830        0.730        1.150
                                                0.161       0.253       0.067
 6.     0.975        0.940        1.230
                                                0.093       0.184       0.032
 7.     1.070        1.130        1.270
                                                0.019       0.060       0.000
 8.     1.090        1.200        1.270
                                                0.054       0.057       0.016
 9.     1.150        1.270        1.290
                                                0.017       0.023       0.023
10.     1.170        1.300        1.320
                                                0.017       0.015       0.008
11.     1.190        1.320        1.330
                                                0.017       0.008       0.015
12.     1.210        1.330        1.350
                                                0.024       0.015       0.007
13.     1.240        1.350        1.360
                                                0.016       0.015       0.007
14.     1.260        1.370        1.370
                                                0.000       0.000      -0.015
15.     1.260        1.370        1.350
                                               -0.016      -0.007      -0.007
16.     1.240        1.360        1.340
                                                0.024       0.022       0.029
17.     1.270        1.390        1.380
                                                0.016       0.021       0.022
18.     1.290        1.420        1.410

                    DAY                           3           3           3

                    MAXIMUM  GROWTH  RATE       1.101       0.976       1.209

                    MEAN  MAXIMUM  GROWTH  RATE 1.095

                    STANDARD  DEVIATION         0.095
                    RENSSELAER  POLYTECHNIC  INSTITUTE
                                TROY,  N.Y.

                 DETERMINATION  OF  DAILY  AND  MAXIMUM  SPECIFIC
                GROWTH  RATES  OF  ALGAL  CULTURES  (BOTTLE  TEST)

SAMPLES  TITLE   20SC51572IJK

        ----------- ABSORBANCE -----------      ------- DAILY GROWTH RATES -------
DAY     BOTTLE 1     BOTTLE 2     BOTTLE 3      BOTTLE 1     BOTTLE 2     BOTTLE 3

 1.      0.100        0.140        0.095
                                                  0.560        0.531        0.521
 2.      0.175        0.238        0.160
                                                  0.721        1.042        1.216
 3.      0.360        0.675        0.540
                                                  0.665        0.336        0.533
 4.      0.700        0.945        0.920
                                                  0.347        0.214        0.290
 5.      0.990        1.170        1.230
                                                  0.201        0.128        0.165
 6.      1.210        1.330        1.450
                                                 -0.051       -0.031       -0.079
 7.      1.150        1.290        1.340
                                                  0.000        0.000       -0.007
 8.      1.150        1.290        1.330
                                                  0.026        0.038        0.007
 9.      1.180        1.340        1.340
                                                  0.025        0.007        0.007
10.      1.210        1.350        1.350
                                                  0.008        0.007        0.007
11.      1.220        1.360        1.360
                                                  0.000        0.007        0.007
12.      1.220        1.370        1.370
                                                  0.008        0.007        0.007
13.      1.230        1.380        1.380
                                                  0.008        0.007        0.007
14.      1.240        1.390        1.390
                                                  0.000       -0.007       -0.007
15.      1.240        1.380        1.380
                                                 -0.008       -0.007       -0.007
16.      1.230        1.370        1.370
                                                  0.016        0.014        0.014
17.      1.250        1.390        1.390
                                                  0.016        0.021        0.042
18.      1.270        1.420        1.450

                     DAY                              3            3            3

                     MAXIMUM  GROWTH  RATE          0.721        1.042        1.216

                     MEAN  MAXIMUM  GROWTH  RATE    0.993

                     STANDARD  DEVIATION            0.205
                    RENSSELAER  POLYTECHNIC  INSTITUTE
                                TROY,  N.Y.

                 DETERMINATION  OF  DAILY  AND  MAXIMUM  SPECIFIC
                GROWTH  RATES  OF  ALGAL  CULTURES  (BOTTLE  TEST)

SAMPLES  TITLE    35SC515721JK

         ----------- ABSORBANCE -----------      ------- DAILY GROWTH RATES -------
DAY      BOTTLE 1     BOTTLE 2     BOTTLE 3      BOTTLE 1    BOTTLE 2     BOTTLE 3

 1.      0.030        0.067        0.030
                                                  0.773       0.751        1.099
 2.      0.065        0.142        0.090
                                                  1.347       1.153        1.253
 3.      0.250        0.450        0.315
                                                  0.732       0.470        0.520
 4.      0.520        0.720        0.530
                                                  0.425       0.245        0.418
 5.      0.795        0.920        0.805
                                                  0.403       0.206        0.303
 6.      1.190        1.130        1.090
                                                  0.008      -0.009       -0.148
 7.      1.200        1.120        0.940
                                                  0.025       0.026        0.052
 8.      1.230        1.150        0.990
                                                  0.032       0.059        0.079
 9.      1.270        1.270        1.070
                                                  0.023      -0.040        0.019
10.      1.300        1.220        1.090
                                                  0.008       0.008        0.018
11.      1.310        1.230        1.110
                                                  0.008       0.016        0.018
12.      1.320        1.250        1.130
                                                  0.008       0.016        0.018
13.      1.330        1.270        1.150
                                                  0.007       0.016        0.009
14.      1.340        1.290        1.160
                                                 -0.015      -0.016        0.000
15.      1.320        1.270        1.160
                                                  0.000       0.000        0.000
16.      1.320        1.270        1.160
                                                  0.030       0.016        0.034
17.      1.360        1.290        1.200
                                                  0.029       0.023        0.008
18.      1.400        1.320        1.210

                      DAY                          3           3            3

                      MAXIMUM  GROWTH  RATE        1.347       1.153        1.253

                      MEAN  MAXIMUM  GROWTH  RATE  1.251

                      STANDARD  DEVIATION          0.079
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                         RENSSELAER  POLYTECHNIC  INSTITUTE
                                    TROY, N.Y.

                    DETERMINATION  OF  DAILY  AND  MAXIMUM  SPECIFIC
                   GROWTH  RATES  OF  ALGAL  CULTURES  (BOTTLE  TEST)

SAMPLES  TITLE   120S0515721JK

          ----------- ABSORBANCE -----------        ------- DAILY GROWTH RATES -------
DAY      BOTTLE 1     BOTTLE 2     BOTTLE 3        BOTTLE 1     BOTTLE 2     BOTTLE 3

 1.       0.012        0.022
                                                    0.606        0.000
 2.       0.022        0.022
                                                    0.598        0.464
 3.       0.040        0.035
                                                    0.486        0.619
 4.       0.065        0.065
                                                    0.693        0.526
 5.       0.130        0.110
                                                    0.836        0.623
 6.       0.300        0.205
                                                    0.466        0.024
 7.       0.478        0.210
                                                    0.417        0.632
 8.       0.725        0.395
                                                    0.322        0.724
 9.       1.000        0.815
                                                    0.113        0.234
10.       1.120        1.030
                                                    0.035        0.084
11.       1.160        1.120
                                                    0.009        0.018
12.       1.170        1.140
                                                    0.017        0.009
13.       1.190        1.150
                                                    0.008        0.017
14.       1.200        1.170
                                                    0.000        0.025
15.       1.200        1.200
                                                    0.008        0.033
16.       1.210        1.240
                                                    0.008       -0.016
17.       1.220        1.220
                                                    0.008       -0.008
18.       1.230        1.210

                       DAY                            6            9

                       MAXIMUM  GROWTH  RATE        0.836        0.724

                       MEAN  MAXIMUM  GROWTH  RATE  0.780

                       STANDARD  DEVIATION          0.056
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